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OTTO VON GUERICKE: A NEGLECTED GENIUS.

BY

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PART II.

V.

Having discovered how to evacuate a vessel Guericke set about performing a whole series of experiments with his new found wonder. In order that we may appreciate why so many of his experiments had a permanent value, emphasis must again be placed upon the novelty of his work. It is true that a partial vacuum had been found as early as the 3rd century before the Christian era by Hero of Alexandria.[1] Hero had found that some air could be expelled from a flask by heating it. If the flask were then sealed and allowed to cool a partial vacuum was obtained. The knowledge thus derived induced Hero to try another experiment. He sucked strongly at the mouth of a flask and then covered the orifice with his thumb. By inverting the flask and dipping it into water it was evident that some air had been withdrawn.

Unhappily, Hero did not apply his knowledge to any practical ends, but used it for the furtherance of religious tricks. By lighting a fire under the altar of a temple he caused air in a tank beneath it to expand and thus to open and close the gates of the temple. Or, he used his knowledge to do conjuring tricks. Water poured into a vase drove out air through the figure of a bird, which was caused to sing by the whistle of escaping air.

Men had to be content with this fragment of knowledge relating to atmospheric pressure and the partial vacuum until Galileo's days. Knowledge had to wait eighteen hundred years before it was advanced by a single step when Galileo discovered that air had weight. Galileo employed the ancient method. He heated air in a flask, sealed it, and

[1] "Pneumatics of Hero of Alexandria." Trans. and ed. by B. Woodcroft. London, 1851.

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allowed the flask to cool. Then it was weighed. Next the seal was broken, air allowed to rush into the flask, and it was observed that the side of the balance bearing the flask, sank, because of the weight of the additional air that had entered.

However, Galileo was far from having achieved a complete vacuum. Nor, since he lacked accurate weighing facilities, was his experiment of the nature to satisfy modern standards. Nevertheless, the result was a substantial addition to the fund of human knowledge, for Galileo had arrived at the definite proof that air had weight. The astounding thing is, that a genius like Galileo, having gone so far, did not take a step further and invent the air-pump. Instead, having found that air had weight he seems to have come to a halt, and not to have made any practical use of this valuable discovery.

It remained for Otto von Guericke to solve the problem of the vacuum. How, he asked himself, can emptiness exert a force, hold down the piston of a water-pump, or draw up water? To answer these questions he embarks upon a series of experiments which consistently added to the store of knowledge.

He placed a lighted candle in a receiver and, after he had exhausted the receiver, he saw the flame of the candle become extinguished. He wisely conjectured that, in order to burn, the candle must derive some form of nourishment from the air. He makes an arresting comment—"combustion is not an annihilation but a transformation of the air" (Bk. III, p. 90). This startling observation passed unnoticed except by John Mayow (1643–1679), to be re-discovered a hundred years later when Lavoisier saw the true meaning of the flame and its combustion.

One of Guericke's most important experiments consisted of weighing a receiver, first when filled with air, and later after it had been exhausted. Demonstrating that it weighed less after exhaustion, Guericke arrived at a rough numerical calculation of its density which was much nearer the mark than was Galileo's. But, he goes further. In making observations from day to day he noticed fluctuations in the apparent weight of the receiver. He took steps to determine what caused the variation in weight, and correctly attributed it to small variations in temperature, atmospheric pressure, and its Archimedian upthrust on the suspended receiver (Book III, p. 108 et seq.). He was to make use of the knowledge derived from these experiments when he came to construct both his barometer and thermometer.

In another experiment he noted that when air from a glass vessel was allowed to expand suddenly into an exhausted receiver, a cloud of moisture formed and revealed the colors of the spectrum. Again, he remarks upon the exhaustion of gases absorbed in liquids, "the liberation of their fragrance" was immediately observed.

Guericke was led to experiment with living animals in a vacuum. He introduced small birds and fish into the evacuated receiver and found

that they expired when the air was exhausted. He realized that air was not only a necessity of life but that breathing was a matter of atmospheric pressure, also. Grapes were found to keep in a vacuum unharmed for six months, and an egg for a whole year (Book III, p. 92).

Then, he found that air was elastic. Parallelling the work of Pascal he carried closed vessels to the summit of a mountain, unsealed them, and found that some air rushed out. He re-sealed the vessels and took them to the foot of the mountain where he repeated the experiment. This time, he observed, that air rushed into the vessels.

But undoubtedly the most spectacular of all his experiments was that conducted at Regensburg in 1654 before the Emperor and the Diet. This was the culmination of his experiments with atmospheric pressure.

Guericke was already familiar with little tricks of showmanship with which his discoveries might be impressed upon the lay mind. He had learned that he could store up a vacuum in a copper sphere by securing the joints with a gasket and covering them with grease. He could thus keep his vacuum for use when he felt in the humor for playing tricks upon his unsuspecting acquaintances. One of these scientific jokes we would like to think was played upon the magistracy and alderman of the city with whom he drank, smoked, and laughed.

A vertical cylinder, solidly fastened down, was provided with a close-fitting piston, which was pulled up by a rope passing over a pulley. This rope was divided into 20 or 30 strands, grasped by the same number of men. The men were invited to draw up the piston, no great task. But Guericke had attached his vacuum sphere to the cylinder and, on opening the stop-cock, the piston was drawn down with such unexpected violence that it pulled the crowd of men holding it, off their feet.

This was not his only preparation for the great demonstration. He had already conducted experiments in which he had learned exactly what force was required to tear asunder the separate halves of a sphere when it was exhausted. Combining this exact knowledge with his gift for showmanship, he staged the Regensburg spectacle with the now famous "Magdeburg hemispheres" by which he is best known.

Taking two copper hemispheres, 20½ inches in diameter and with snug fitting edges, he placed them together and exhausted the globe they formed. A team of eight horses was now attached by ropes to each hemisphere. With much tugging and straining the two teams pulled in opposite directions—a sixteen horse-power tug-of-war! The only man in the group of spectators who would have been astonished had a smaller number of horses torn the globe asunder, was Guericke. He knew exactly how much energy the horses must develop to force the hemispheres apart, and he also knew how difficult it is to make sixteen horses pull in unison so that their power is not wasted. Even at that early stage science was displaying a certain amount of worldly wisdom when dealing with the world!

Naturally, the renown of this demonstration drew visitors to his home in Magdeburg, so that it became necessary, not to disappoint them, to have an experimental demonstration ready for instant display. When he was importuned to give a sample of his scientific magic a great deal of time was wasted while the globe was exhausted by his slow-working pump. Therefore Guericke developed an apparatus which made waiting unnecessary. This consisted of a copper vessel with a stop-cock underneath and a pipe which passed through the floor of his laboratory into the chamber below where workmen were held in readiness to assist in the performance of experiments. When a series of experiments were in progress which reduced the rarefaction of the principal vessel, the workmen were always at hand to restore the high stage of rarefaction that Guericke demanded for his experiments.

With such apparatus as we have described it is not surprising that his son calculated Guericke's expense upon his experiments as having exceeded 20,000 thalers, a sum that represented very much more in those days than its modern equivalent of $20,000.[2]

It was only natural that Guericke should be the first to carry out experiments concerning the relation of the air to the perception of sound. The belief that air was the medium through which sound was transmitted had existed since the time of Aristotle, but it was so imperfectly understood that it was associated with some rather droll explanations. Some thinkers flirted with the belief that it was only a part of the air which was involved in the propagation of sound. It was also suggested that the function of transmission was allocated to only certain atoms of air. This latter theory was accepted and elaborated into a fuller theory in which it was contended that sounds of a different pitch were carried severally by atoms of corresponding elasticity.[3] Without the aid of the air-pump no advance could have been made upon this pure speculation. Guericke exploded it, and similar, far-fetched theories by a single experiment which must have escaped the attention of the Academicians.

He demonstrated that sound requires a medium of transmission. This was done by hanging a bell, with a clock-work arrangement for making it strike, on a thread inside the receiver of his air-pump. He then began to exhaust the receiver. As the exhaustion advanced, Guericke observed that the sound of the ringing bell became fainter and fainter until it became entirely inaudible. Satisfied that air was the medium through which sound was transmitted he next applied himself to the determination of other media. By means of other experiments he ascertained that sounds can be transmitted through water and even through solids (Book III, p. 91).

Although he is quite correct in his conclusion that water is a suitable

[2] Gerland, E. Geschichte der Physik. 1913, p. 508.

[3] Memoires de l'Académie Royale des Sciences. 1737.

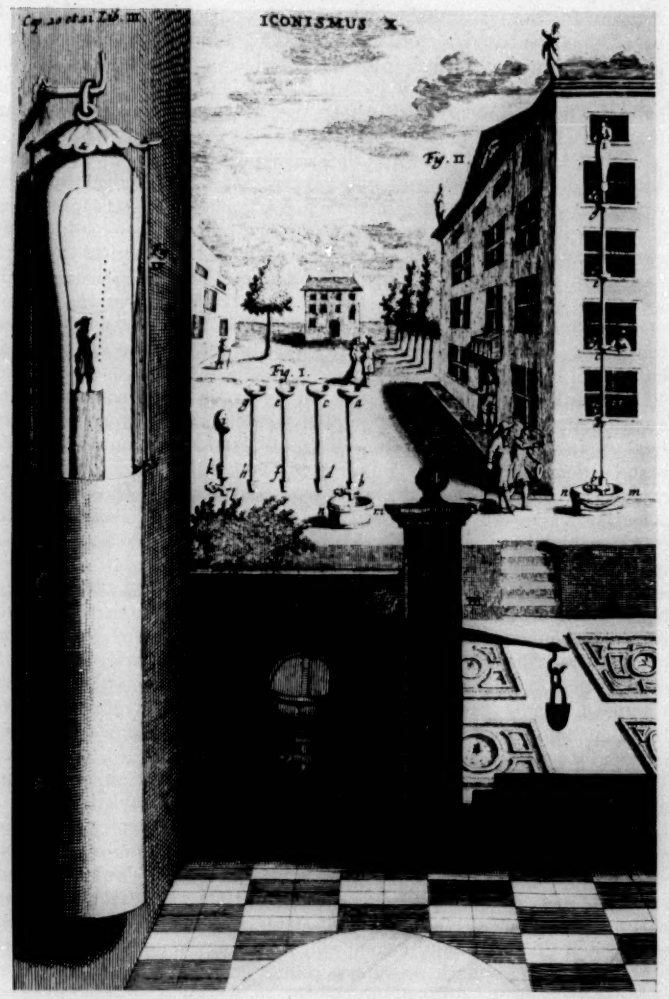

FIG. 4. Guericke's great barometer (From the *Experimenta Nova*).

medium for the transmission of sound, the experiment upon which his conclusion was based is more ingenious than convincing. He lowered a glass flask containing a bell into a fish bowl. Guericke then discovered that the fish would come for food at the ringing of the bell. However, only the fish can assert with surety that it was sound, and not sight, that served as the lure.

Guericke proved for the first time that the intensity of a sound varies with the density of the air in which it originates. This idea originated with him, and Boyle and Papin made his experiment the basis for further study. Priestly made investigations to ascertain whether the intensity of sound might be different in other gases; Chaldini experimented with various media for the transmission of sound, and Biet measured their velocities. But it was Otto von Guericke who had given the science of sound its initial impulse. By his own effort he had rescued it from the foolish belief that special particles of air attended to the needs of individual tones.

Before leaving the experiments with the air pump some mention must be made of Guericke's attempt to convert his discovery to a practical use in military operations. He constructed a weapon which might best be described as a rarefied-air gun. The bullet was propelled by external pressure through a suddenly exhausted tube. It thrust aside a leather valve that closed the tube, and departed on its flight with considerable velocity. No armed forces appear to have adopted this ingenious weapon.

We have alluded to the confusion which arose in the 17th century between the work of Guericke and Robert Boyle in England. The truth is that Boyle added little to what the former had revealed. However, he was first to observe that the vacuum did not interfere with the propagation of light. He experimented to ascertain whether the vacuum had any effect upon magnetism, and faithfully records that it had not. Boyle was the first to place a barometer under the glass receiver of an air-pump and to observe the effect of exhaustion upon it. The ebullition of heated fluids and the freezing of water on exhaustion of the vessel containing it were also first observed by Boyle.

Yet Guericke was the first to observe the expansive force of the air and Boyle (and, later, Mariotte) pursued investigations of this quality which enabled Boyle to discover the law associated with his name. As a result of Guericke's work it became apparent that it was not nature but natural philosophers who could not abide a vacuum. Once he had established this fact many incomprehensible things about the air were explained. Atmospheric pressure and its effect upon a column of water or mercury could be studied and the barometer could be standardized. Because air was found to have weight it became clear that the blanket of air surrounding the earth must be exerting a great pressure upon the earth's surface.

The discovery of the vacuum created by Guericke's air-pump opened up a wide field of application, yet strange to say, very little work of any importance was performed upon the physical properties of gases until the beginning of the 19th century when J. A. C. Charles discovered the law which governed their expansion by heat.

VI.

In Guericke's day the phenomenon of suction, the action of pumps and syringes, were explained away by attributing to nature the power of seizing hold of the first adjacent thing, whatever it might be, and immediately filling up with it any vacant space which chanced to exist. This was the effect of nature's supposed abhorrence of the vacuum and her way of preventing its creation. One can readily see how such a view can be supported by a people deprived of all scientific instruments, for the visible phenomena approximate to the view in so many ways.

Then one day Galileo was called upon to explain the cause of failure of a monastery pump. A particularly deep well had been sunk in the monastery garden, but the pump erected at its mouth would not raise water to the surface. On investigating the conditions Galileo found that no amount of pumping would induce the water to rise higher than about 30 feet, whereupon he is asserted to have made the dry comment: "Nature abhors a vacuum only to the extent of thirty feet." But he was either not able or did not attempt to explain the phenomenon any further.

One of his pupils, Torricelli, was not content to leave the problem in this unsatisfactory state. He argued that, if water rises in a tube it cannot be because the vacuum above draws it upward. He suspected that it must be the weight of the air resting on the outside water which pushed it up the tube. When the water reached its maximum height in the tube, the downward pressure at the foot of the column, due to its weight, he thought, must exactly equal the upward pressure exerted by the air pressing on the water outside the tube. Such a column should measure the pressure of the air.

Apparently, Torricelli had no great desire to construct and try to manipulate a column of water thirty feet high. He cast about for a more expedient design for his atmospheric pressure measuring device. He hit upon an idea that was to have the happiest outcome. Mercury was fourteen times heavier than water; therefore, he argued, a column of mercury only 1/14 the height should respond in precisely the same proportions as a column of water thirty feet high.

This was Torricelli's theory, and a theory it remained until, in the year 1643, Viviani proved its truth by experiment.

Unaware that Torricelli had devised a simpler solution to the problem, Guericke had pursued his independent way, which chanced to be the hard way. He first heard of Torricelli's principle from Valerianus

Magnus when they met at Regensberg in 1654 and the famous Magdeburg hemispheres had created keen discussion. Undeterred by the incommodious length of a column of water he had constructed the very instrument that had looked so forbidding to Torricelli.

Guericke had already learned a great deal about the weight and the elasticity of the air by his experiments with the air-pump, but it was a problem in practical engineering that had turned his mind to the solution of the problem of raising water above the thirty feet level. In building a home, very probably at the time of the restoration of the city after Tilly's devastation, he found that it was possible to raise water to the third floor of his home, but not to the fourth. This was a direct challenge to his intellect.

In order to ascertain the exact height to which water might be raised by suction, he constructed a special apparatus which was nothing more nor less than a barometer, in which water was used instead of a column of mercury. It consisted of four brass tubes joined end to end so that they formed a vertical pipe. This was surmounted by a glass receiver. At the lower end of the pipe was a tap which was immersed in a vessel containing water. At first this tap was kept closed, and the pipe and receiver were filled with water. On the tap being opened the water sank to a level which could be observed accurately in the glass receiver.

Eventually the glass receiver came to be marked with a graduated scale and the level of the water in it was indicated by the figure of a wooden mannikin with a finger pointing to the inscribed scale. The differences in the levels of water in the pipe and in the vessel at its base were read by the aid of a plumb-line.

This was the mannikin which led the Magdeburgians to suspect that their Burghermaster was practicing sorcery. For he had built a framework around the instrument, concealing everything but the tell-tale mannikin, whose weather predictions might be heeded or not according to the degree of one's piety. However, behind the screen, Guericke was making observations to good purpose.

As a result of these observations he correctly attributed the rise and fall of the water in the pipe to natural variations in the pressure of the atmosphere, and not to any black magic. How or why did this pressure vary from day to day? He extended his investigations over a long period of time and compared the fluctuations with actual changes in the weather. He thus assembled data which enabled him to make an accurate forecast of the great storm of 1660 from a sudden drop in his column of water. This was the first occasion on which weather prediction was based upon a scientific principle.

This forecast was something of a triumph. It proved that his observations and comparisons had borne fruit. It also proved that Guericke had the right type of mind to interpret what he saw. His

conclusions upon the co-relation of atmospheric pressure and the weather were just as inacceptable as his ideas upon the vacuum. They provoked many controversies and gave rise to speculations that continued for several decades before they were recognized.

Monconys, the philosophical police lieutenant of Lyons, mentions in his *Voyages* a meteorological instrument designed and constructed by Guericke, which recorded hourly temperature, direction of the wind, rainfall, and the amount of snow and hail. Although Bolton [4] gives this his serious attention, I am inclined to think that it was not a single instrument but rather the collection of apparatus that Guericke had gathered in his study of the weather. Monconys was deceived (but probably with deliberation this time) upon another matter connected

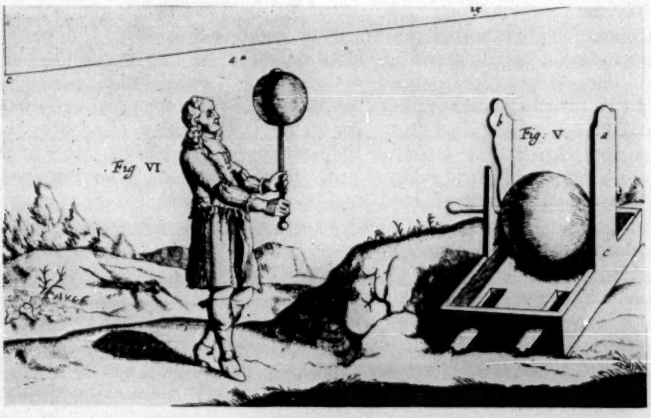

FIG. 5. The first electro-static machine (From Guericke's *Experimenta Nova*).

with Guericke's work, so that he is not entirely above suspicion of blissful innocence that is vulnerable to deceit. In any event, I have found no other mention of this comprehensive instrument, and it is unlikely that Guericke would have failed to make allusion to it in his writing.

VII.

Upon slender, but none the less convincing, evidence, Galileo is credited with being the first man of science to think of utilizing the expansion of the air for the purpose of measuring temperature. Galileo's device contained a fundamental defect and it remained for Guericke to correct this, but their combined achievement appears very trifling unless

[4] Bolton, H. C. "Evolution of the Thermometer" (Easton, Pa., 1900).

the reader recalls the mistaken association of ideas about temperature that prevailed before their time. Then, and only then, is the importance of their work realized.

At the beginning of the 17th century no clear conception had been formed on the nature of heat. The element called "fire" was held to be responsible for the phenomena which we now call heat, flame, and fire. Bacon caught a glimpse of the truth that heat may be vibration of atoms, but the idea made such little headway that Robert Boyle, who favored this view, occasionally lapses by alluding to the orthodox "fire atoms." The idea that Galileo, Torricelli, or Guericke used thermometers as measures of temperature would be an exaggeration. They used the instruments more as indicators than as measures. It was not until the year 1714 that Fahrenheit got the happy idea of his reproducible scale that the thermometer could be used for measuring with any degree of accuracy. However, his work was based upon what Galileo and Guericke had prepared as a foundation.

The air-thermometer used by Galileo was a simple tube, open at one end and with a closed bulb at the other end. The open end was placed in a vessel containing water. As the air in the bulb expanded or contracted with the rise or fall of temperature, it caused the water in the tube to move upward or downward. Since Galileo speaks of "degrees" of heat a scale of some nature must have accompanied his thermometer. But it had its limitations. An air-thermometer of this construction suffers from the defect of being affected by changes in atmospheric pressure, so that it could be used only for comparative measurements made within very short periods of time.

Guericke was responsible, some time between 1661 and 1663, for an improvement which compensated for this variation in atmospheric pressure. The instrument he devised was the result of a gradual evolution achieved through experimentation with various types of thermometer. His instrument consisted of a copper sphere, embellished with the legend "Mobile Perpetuum," to which was joined a long tube of the same metal, one inch in diameter. This tube was bent in the shape of a narrow U, the long arm of which was connected to the copper sphere, while the shorter arm was open. A certain amount of alcohol was put inside the tube. A tiny cup of brass foil was floated on the surface of the alcohol column, and to this was attached a cord that ran directly upward and was passed around a wheel hung on the underside of the globe. Dangling at the loose end of the cord was the figure of an angel.

A valve in the copper sphere enabled Guericke to withdraw, with the aid of his air-pump, enough air to adjust the column of alcohol and, consequently, the height of the angelic figure, which pointed to the reading on the scale. For he had a scale. True it was a modest affair, for it consisted of only seven degrees of temperature—very cold, cold, cool, temperate, warm, very warm, and hot.

Guericke's great contribution to the accuracy of the thermometer lay in the valve which he introduced into the copper sphere to compensate for variations in atmospheric pressure by co-related variations in the volume of air enclosed within the tube and the sphere.

VIII.

Finally, this extraordinary man laid the foundation of the science of electricity, constructed the earliest mechanical device for generating electrical charges, and made discoveries of such a fundamental nature that, since they were generally disregarded, all had to be re-discovered again independently, to the great credit of the new discoverers.

In his day practically nothing was known of electricity except the four natural emanations that had been known from ancient times—St. Elmo's fire, the electric eel, lightning, and the attraction of rubbed amber. These forms were so far removed from one another that ancient man may be forgiven for failing to recognize them as different aspects of the same phenomenon. The variety of electrical aspects was not co-ordinated until Franklin's work provided the connection.

In the year 1600 William Gilbert, the English physician, published the results of seventeen years devoted to the investigation into the problems of electricity and magnetism.[5] In this book Gilbert listed other substances which possessed amber-like qualities of attracting light bodies when rubbed. These he called *electrics*, from *elektron*, the Greek word for amber. However, it is singular that Gilbert with all his observations of electrical attraction failed to observe the effect of electrical repulsion.

Since magnetism was of more practical importance than was electricity at that time, Gilbert's followers devoted themselves exclusively to the study of the former. They did not advance the knowledge of electricity beyond the point where Gilbert had left it. It remained for Otto von Guericke, with his passion for experiment and his ingenious instrument-making ability, to make the next advances.

As a result of numerous experiments Gilbert had arrived at the conclusion that the lodestone and all other magnetic substances have retained the potency of the earth's essential core; that the lodestone was a fragment of the primal form of a magnetic earth; and that the earth itself was a gigantic magnet. He was forced to this conclusion by his observations of the effects produced by the lodestone and the earth upon adjacent bodies.

Here was one picture of the earth as conceived by a man who derived his theory from the result of experimentation. Guericke, it will be recalled, was seeking to define a conception of the universe, and he adopted the same method of basing conclusions upon experiments.

[5] Gilbert, W. "De Magnete, Magneticisque Corporibus, et de magno magnete tellure; Physiologia Nova." (London, 1600.)

Anyone reading the conclusions would be amazed unless they were aware of the experiments upon which he based them. Since the experiments are of much greater value to us than the conclusions he derived from them, we will reserve consideration of these until we have examined that portion of his book which has, so far, been ignored. We have no justification for this unscientific method except that it was favored by Guericke himself.

In Book IV of the *Experimenta Nova* he is concerned with what he calls "the mundane virtues." Just as Gilbert compares the earth with a globe-shaped lodestone, so Guericke derives his knowledge of the earth's "virtues" from the behavior of a sphere of sulphur which he employed as a static-electric machine. Guericke has a great deal to say upon the mundane virtues and it will repay us to hear him say it in his inimitable manner, for we are listening to the first real student of electricity, who translates hitherto unobserved phenomena into terms of universal forces.

One is tempted to transcribe "mundane virtues" into "natural forces," but this does not convey Guericke's meaning exactly. He says: "These virtues are either essential or casual; they are effluvia of physical bodies, enter the constitution of and are given off by these bodies. A distinction must be drawn between the virtues which are constitutional and which radiate from the body, and those which penetrate and are absorbed by physical bodies. The casual virtues are those which are absorbed, and the essential virtues are those which are innate and cannot be separated from the body without changing its state." [6]

Again, these virtues are corporeal and incorporeal. The former are so called because they cannot penetrate solid bodies like glass and metal. Air is a corporeal virtue. There are many incorporeal virtues, although because of our defective senses not all of them are perceptible. Those we are best able to perceive come from the earth and the sun. From the earth come impulsive, conservative, directive, turning, sounding, and other virtues. From the sun come the light and color virtues.

The impulsive virtue appears to be no other than momentum, since Guericke bases it upon the behavior of a stone suspended on a string and rotating in a circle, the ascension of pebbles on the side of a rapidly rotating bowl, the swinging of a pendulum, and the movement of planets and their satellites.

His conservative virtue we should call gravitation, for Guericke says it is the virtue which is the cause of all bodies being drawn to-

[6] "Haec virtutes neque sunt Substantiae neque Accidentia, sed sunt Effluvienta Corporum Mundanorum, quae istis corporibus insunt & ex eis effluunt. Differentia tamen habenda est quatenus Corpori alicui originaliter insunt ex coque effluunt; & quatenus in aliud influunt ab coque recipiuntur; Nam illius in quod influunt sunt Accidentia; ex quo autem effluunt, ejus sunt innatae Virtutes, quae non sine maximo detrimento seu formae interitu, abesse possunt." Book IV, p. 125.

gether, which is not attraction, but is rather a striving for cohesion and a will for self-preservation.

The explusive virtue is a quality he supposes the earth to possess because it is analogous to electrical repulsion. He finds it also in the motions of the planets around the sun, and of their satellites around the planets. Turning virtue is simply the rotation of a body on its axis. Directing virtue is Gilbert's "verticity," the magnetic force which, he thought, adjusted the earth's axis in space and prevented its nutation.

The sounding virtue is that which causes the sensation of sound, but Guericke finds that it is produced "by the friction of bodies."

The heating virtue is explained in a curious manner (IV, p. 140). The explanation is based upon the glass tear-drops which Prince Rupprecht von der Pfalz introduced from England about 1661. Monconys may have described them to Guericke for he and the French scientist Gassendi had experimented with them.[7] Guericke had heard a great deal about these tear-drops and, although he had not seen them, he offers an ingenious explanation of his heating virtue with their aid. A curiosity of these glass articles was that the ball would resist hammer strokes, but the whole article fell into fragments when the solid tip was broken off.

Guericke says that the molten glass was allowed to fall drop by drop into cold water. On the outside the tear-drops were as smooth as glass, but inside the particles were hollow and porous through the penetration of heat. Heat, he alleges, makes all particles expand and become porous. When the hot glass droplet came into contact with the cold water the particles on the surface were instantly hardened and assumed the nature of glass. But the heat escaped as an incorporeal virtue and left empty the small spaces it had occupied, thus leaving the interior particles disconnected. Consequently when a portion of the glass was broken off, the outer air rushed into the vacua with great force and noise, and transformed into dust all the particles made porous by heat.

We have drawn attention to this account, partly because of the unusual interest aroused in those days by the glass tear-drops, and partly to illustrate Guericke's methods. If this account shows how inexact was his conception of the "heating virtue," it shows how he was developing a scientific method of approach to a problem, and how clearly he recognized the universal application of the air's pressure.

Not all his shots fell as short of the mark as this one. We can discern some near approaches to the truth in his mundane virtues. Although he lacked an understanding of the real truth it is quite clear that Guericke had a perception of the resemblances between the phenomena due to the play of natural forces, and had struggled to clarify

[7] Poggendorff, J. C. "Geschichte der Physik" (Leipsig, 1879), p. 412.

indistinct notions of a co-relation between them. We have seen the manner in which he perceives the different "virtues" of the earth, how they are all different, and yet how they have certain resemblances. He tries to reduce them to a common denominator. In his perception of their differences he concedes that the natural phenomena—light, gravity, sound, etc.—are the very essence of a physical body and emanate from it. But in his study of electricity and magnetism he refuses to follow Gilbert in his belief that the earth is a great magnet.

In Guericke's opinion the earth's movements were controlled by the radiation of the sun and its own "turning virtue," which two forces would result in an uneven balance. He concludes, therefore, that nature steps in to provide a directive force "so that it does not sway this way and that, not even on account of the friction of the sun's rays, and consequently it does not wabble in its daily rotation, and so change the time of the year and the length of the days." For this reason, he infers, Gilbert was wrong in supposing that the earth was a magnet.

But that is not all. He harks all the way back to Aristarchus of Samos, who lived about 310–230 B.C., and chides him for rejecting the belief that the earth had an attracting and a repelling force. Guericke held that this belief harmonizes with reason. "For if the earth has the power of attracting those things which are agreeable to it, it will likewise have the power of repelling those things which injure or do not please it."

These ideas were so revolutionary that it is only reasonable to suppose that a man of Guericke's intellectual method would not produce them "out of his own head." He definitely rejected conclusions based upon speculation and imagination. Exactly as he had developed his ideas upon space from experiments with atmospheric pressure, so he now based his conceptions of the natural forces (or mundane virtues, as he prefers to call them) upon electrical experiments which were dangerously novel. What he learned from those experiments we shall see in a moment; just now we wish to clarify his argument by emphasizing his processes. To explain his ideas upon space and the vacuum he was compelled to create the instrument—the air-pump. Now, in order to ascertain the nature of the earth's virtues he is compelled to invent the electrical machine so that he may conduct experiments upon which to construct a theory. Later, we must return to the electrical experiments which are of much greater importance than his views of the earth's virtues.

He argues, that if the earth is a magnet it must be endowed with all the magnetic virtues. Not only must it possess directive power but it must also have attractive power. Then he goes on to show by comparisons of the various virtues that the magnetic power of the earth simply holds and adjusts its axis in space, and exerts no attractive force upon any external body. In comparing the "conservative virtue"

(which is a somewhat shadowy conception of gravity) with the earth's "directive virtue," he declares that the former "attracts all bodies not only in the region of its poles but everywhere. Bodies are not changed but are held by the conservative virtue."

Let it not be overlooked that Guericke was writing twenty-five years before Newton's *Principia* was published. Left to his own resources Guericke arrived at the conclusion that this "conservative virtue" was similar to electrical attraction because it attracted from all points, differing in that respect from magnetic attraction which is found only at the poles of the magnet. Moreover, he finds an analogy between the conservative virtue exerted by the earth on external bodies and the electrical attraction of his sulphur globe.

This is in strong contrast to Gilbert's contention that the earth's matter was brought together and held together by magnetic attraction.

Now let us see by what possible course of experimentation Guericke could have arrived at these views at a time when electricity was known only in its sportive moods. Perhaps if we recall Monconys' astonishment when he was treated to a private demonstration of the electrical machine, we may recapture some of the atmosphere of awe, mystery, and wonder that surrounded the first electrical experiments. What the French seeker after truth had witnessed was a demonstration of the earth's conservative virtue, a thing unknown to his contemporaries who had not been admitted to Guericke's confidence.

Gilbert had made his "terrella," or globe, of a magnet, which accounts for all his theories conforming to the magnetic theory of the earth's mass. Guericke made his globe of an electric and blundered into the same erroneous generalizations.

Perhaps Guericke wished to inspire Monconys, who had travelled so far on his innocent mission, with a feeling of mystery which would make the Frenchman feel that his journey was worth while. Perhaps the whole environment of the laboratory in Magdeburg was judged too commonplace to reward the traveller from a far country so that a little misinformation would create a more profound impression. Accordingly, Monconys was sent on his way rejoicing in the innocent deception that he had witnessed a demonstration performed by a globe composed of nine minerals. It may have been that the Frenchman did not care to admit that he had travelled so far to witness an experiment with a handful of common sulphur, and he may have added eight minerals to the one original in order to exult over his superior wisdom.

In any event Guericke has given a faithful picture of his first electrical machine and a description of his experiments that are free from deception.

"Take a sphere of glass called a vial, of about the size of an infant's head;" he writes, "put in it sulphur that has been pulverized in a mortar, and liquefy by placing it near a fire. When this has become

cool, break the (glass) sphere, take out the globe, and keep it in a dry place" (IV, p. 147).

That was all there was to it. Just plain sulphur. Then a hole was bored through the sphere and an iron rod passed through to serve as an axis when it had to be rotated. The question naturally arises: why go to all the trouble of filling a glass sphere with sulphur? Why not use the glass sphere itself? Guericke very probably did try the glass only to learn that it was extremely difficult to drill a hole, smooth and round enough for his purpose, in the imperfect glass of his time and place.

But with the simple instrument that he had made Guericke proceeded to make experiments illustrating his theories of the universe. He secured confirmation of "impulsive virtue" or momentum by hurling the ball from his hand. Because it was heavier than a wooden ball he could throw it further.

Next, he proceeded to obtain justification for his "conservative virtue" by resting the iron axis of the globe upon two supports, about "a handsbreath above the base," with fragments of thin paper, gold leaf, and silver filings strewn underneath. Guericke advises that those who wish to repeat this experiment should "stroke the globe with the dry palm so that it be submitted to friction thus twice or thrice. Then will it attract the fragments and, when turned on its axis, will take them along with itself. In this manner is placed before the eyes the terrestial globe, as it were, which, by attracting all animals and other things on its surface, sustains them and takes them around with itself in its daily motion."

Now comes the account of a real discovery. Cabreus had seen chaff move away from an electrified object but had not profitted from his observation. Guericke also observed this effect of electric repulsion but he grasped its significance. Here is how he describes it:

"Even the expulsive virtue is to be seen in this globe, namely when it is taken from its support to the hand and is rubbed or stroked in the aforesaid manner with the dry hand, for it not only attracts but repels again from itself little bodies of this sort (in proportion to their temper), nor does it receive them until they have touched something else."

There you have the first observation of the discharge of an electrified body on contact with an object other than the electric, and its subsequent re-attraction after discharge. But that is not what we are after at the moment. Let Guericke proceed with his experiment.

He removes the globe from its support and holds it in his hand with the axis vertical. He rubs it with his palm to excite the globe and then uses it to repel a feather. When the feather is suspended in the air, Guericke advances the globe driving the feather before him around the room.

He notes that when it is pursued around the room it "approaches

the points of any object whatever before it, and it is possible to bring it where it may cling to the nose of a spectator."

There we have Guericke anticipating Benjamin Franklin in realizing the effect of pointed conductors in drawing off an electric charge. But more of this later.

For the time being he proceeds to observe the strange behavior of his charged feather, and reels off discoveries one after the other. He observed the dissipation of a charge by heat. Here is his account: "If one places a lighted candle upon the table and drives the feather to a distance of one hand's breadth from the candle, the feather suddenly recedes, and flies to the globe as a sort of guard."

Then he finds that the same face of the feather which was caught up by the globe and then repelled remains unchanged while within the field, so that if the globe is put over the feather, "this will invert itself in the air and present the same face always to the globe." Guericke then plunges after his main hypothesis by announcing "that it is from the same cause that the moon always presents the same face toward the earth."

This analogy between electric attraction and planetary attraction was inexact, of course, for the latter is proportional to the mass of the body, while electric attraction is proportionate to the surface. But if the conclusion advanced by Guericke is inadmissible the observation of the repulsion of a body after it had been attracted was accurate enough. Nevertheless, the idea that this experiment provided adequate explanation for the moon always turning the same face to the earth was just the kind of idea that would appeal to the students of the 17th century. Why they should have ignored it is difficult to explain. Even Priestley wondered why later "electricians" had overlooked this experiment for it impressed him as decidedly curious.

The feather continued to perform some extraordinary tricks under electrification. "When the feather begins to unfold its primules on the globe and you approach your finger or something else toward it, it will fly to it, and then recede to the globe. This it will do several times. But if you approach a linen thread to the feather all its primules become straightway attached to the globe, and it will lie for quite a time as if dead, until they again erect and extend themselves."

Guericke finds that the feather is alternately charged and discharged in an odd way. If the excited globe is caused to rotate and a soft feather is placed underneath it "the globe will then attract the feather many times and drive it around away from itself into the nearest place underneath, and continue this for some hours. . . . It does not allow the feather to approach until it has cast it against something else, perhaps in order that it may extract something therefrom."

Gilbert had seen that an iron rod made magnetic at one end becomes magnetized at the other end, but no one before Guericke had noted the

transference of electricity from one body to another by conduction. He also observes that electricity is transferred instantaneously from end to end of a conductor. He says that this experiment "ocularly shows that the sulphur globe having been previously excited by rubbing, can exercise likewise its virtue through a linen thread an ell or more in length, and there attract something."

Having already noted that "if you let down almost to the globe a linen thread suspended from above, and try to touch it with a finger or something else, the thread recedes and will not allow the finger to meet it," he proceeds to make another experiment. He fastens the thread to a sharp stick fastened to the table, so that the thread hangs vertically with the loose end about an inch from some other body. Then he excites the globe and brings it to the sharpened point of the stick from which the thread is suspended. Immediately the loose end of the thread is drawn to the adjacent body.

There is a great deal in this simple experiment when it is studied in detail. Guericke had conceived the idea of passing an electric charge over a line; imparting the charge to the conductor by connecting the latter to the pointed end of a fixed support; causing the end of the charged thread to move toward or away from the juxtaposed body by movements of the excited globe.

Although the writer makes no pretence to be a physicist he sees in this simple experiment of Guericke's more original features than are to be found in any other experiment in the entire history of electricity. Here is the discovery of conduction, induction, the discharging value of a pointed conductor—and all this by a man who lived and worked in the 17th century, a man whose name rarely occurs in the chapter on electricity in any general physics text-book. To a layman the whole electric telegraph lies in embryo in that one experiment.

Great as this achievement is what is one to make of another observation by Guericke?

"If you take a globe with you into a dark room and rub it, especially at night, light will result."

Otto von Guericke was the first man to look upon artificially produced electric light!

It is true that the glow produced by rubbing a sulphur globe was so feeble that its discoverer likens it to the phosphorescent glow produced by breaking lump sugar in a darkened room. Nevertheless, this experiment made a profound impression upon one or two other students. Boyle repeated it without adding anything to what Guericke had done, but it was Hawksbee's hope to extend Boyle's effort that induced him to design an improved electrical machine which would produce a better spark, and thus started research into electricity upon two continents.

Although Guericke also observed the crackling and snapping of the discharge, he did not associate it with the brush discharge he saw.

"There is also the virtue of sound within the globe," he comments, "for when it is carried in the hand and brought to the ear, roarings and cracklings may be heard." And that is all.

IX.

Strange as it may appear that Guericke should have been so neglected in his character of original experimenter and scientific discoverer, it is equally strange that the man who continued his experiments should have suffered a like neglect. Stephen Gray of Charterhouse was able to extend some of Guericke's work and to describe more explicitly the phenomenon of electrical conduction in a series of experiments that are worthy of more attention than they have received. One is almost driven to the conclusion that the world's neglect has been deliberate.

Although a reader will seek in vain for any mention of Guericke's name in the voluminous works of Franklin, it was while studying static charges of electricity upon a development of Guericke's elementary invention, that Franklin obtained his knowledge of the science. It was from theories formed by practice with these machines that Franklin was encouraged to make his kite experiment.

It was from this humble beginning that the modern electrical industry has sprung. This in itself should ensure Guericke's immortality and we must supplement this achievement with others in pneumatics that furnished so much that was new and wonderful.

The story of science contains many romances but few exceed in interest the story we have outlined here. Guericke's life will bear a scrutiny that few others could endure. The sweat and strife of some careers in public life tarnishes the otherwise brilliant luster. But Guericke's life as burghermaster reflects as great an honor as his life in science. It is to such examples that we should turn for encouragement to meet the future.

With the baring of each new mystery by modern science the layman sees the complexities of life being strangely simplified. He does not see that with the baring of each new mystery the natural world becomes more mysterious than ever. The mystery becomes more impenetrable as its variety increases. There is refreshment in turning back the pages to the simple stage of modern science when it was taking its first uncertain steps. And there is encouragement, too.

For, enclosed by an intangible night we watch the working of the great microcosm, peering through the little window science provides. We yearn to hear the heart throb of a slumbering world, we delude ourselves with the thought of knowing. The Silence is alive with voices we cannot hear.

Conquest Over Ice.—Plane Talk, a publication by Consolidated Vultee Aircraft Corporation, reminds us that ice on wings has always been a hazard that airmen dreaded almost more than anything else. The war has increased exposure to that hazard. For it has made it necessary to fly planes at great altitudes where intense cold prevails; to fly them in far northern regions; to fly them in the icy mists that overhang northern seas; and to fly them regardless of weather conditions. In the middle 30's a de-icer was invented that was the best approach to the icing problem up to that time. It consisted of a giant rubber overshoe fitted over the leading edges of the wings and other parts, where ice interferes with the aerodynamics of the plane. By inflating and deflating the "overshoe" the ice was cracked after it was formed. Hence the name de-icer. But this ingenious device could be regarded only as a makeshift. It did not prevent formation of ice. It did not overcome the loss in lift caused by irregular caking of ice. A new thermal anti-icer is designed to prevent ice from forming at all. It will do this even in temperatures far below zero. Its principle is simple—a matter of heating the leading edges by the indirect use of formerly wasted exhaust gases. Although its essence is simple, the practical application of this idea has taken six years of research and experiment. The idea was conceived and in part developed by the National Advisory Committee for Aeronautics; the detail work leading to perfection was done jointly by Consolidated Vultee engineers and Lewis A. Rodert, senior engineer of the N. A. C. A. As now made practical, the thermal anti-icer uses the hot exhaust gases to heat air, by means of heat exchangers in the engine exhaust pipes. The air is then circulated through wings and tail surfaces with controlled initial temperatures ranging as high as 350 degrees F. This heated air keeps the aluminum alloy of the leading edges at a temperature of 60 degrees F. (28 degrees above freezing) even when the outside air temperature is 40 degrees below zero. Tests in far northern latitudes have now been completed, with the simple device functioning perfectly.

R. H. O.

THE BELLOWS ACCELEROMETER.

BY

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The usual type of accelerometer employs some form of pendulum for the active element. This pendulum may have the form of a mass free to rotate about some point or it may have the form of a cantilever beam clamped at one end to a stationary point with the other end free to move under the action of accelerating forces.

An essential requirement for any form of accelerometer is that it be adequately damped. Damping may be accomplished in several ways: by friction, by a dash pot, and by electromagnetic induction. Any one of these methods has its disadvantages. If friction is used the usual troubles of erratic behavior are always present. If a dash pot, employing a liquid, is used there is always present the possibility of leakage of the liquid and if subjected to change in temperature the damping action changes due to a change of viscosity of the liquid. Electromagnetic damping is theoretically correct, but if a strong magnetic field is necessary it is sometimes inconvenient to incorporate a sufficiently strong magnetic field in the instrument without making it large and heavy.

The instrument here described employs a sylphon bellows as an active element, and by taking advantage of the form of the bellows it is used as a means of damping. The manner in which the sylphon bellows has been employed as the active element of an accelerometer will be briefly described. Fig. 1 shows the construction of the active element of the accelerometer. The metallic sylphon bellows (a) is shown mounted on a base plate (b) to which it is attached with solder. The top end of the bellows is closed by a circular plate (c) to which it is also soldered. Attached to the top circular plate within the bellows are cylindrical masses (d, d, d) through which extends the axial rod (e). Surrounding the sylphon bellows is a cylindrical cup (f) to whose bottom cover (g) the base plate of the bellows is attached by screws. The bellows and cup assembly is made reasonably airtight except for the clearance holes in the top and base of the cup through which the ends of the axial rod extend. To control the entrance of air into the cup and its exit from the bellows upon compression, two needle valves (h) and (i) are provided.

To permit a free movement of the axial rod through the opening of the surrounding cup upon compression or extension of the bellows

during acceleration, each end is provided with three miniature ball bearings (j), (k), and (l) at one end and three others (m), (n), and (o) at the other end disposed radially about the rod with their axes perpendicular to the length of the rod. By this arrangement the rod can move axially with very little friction. Means are provided by which the bearings may be adjusted so as to prevent rubbing of the rod against the sides of the openings of the cup. The action of the bellows accelerometer element is as follows: During acceleration the cylindrical masses compress or expand the bellows. By measuring the displacement of the mass during a known acceleration the instrument may be calibrated.

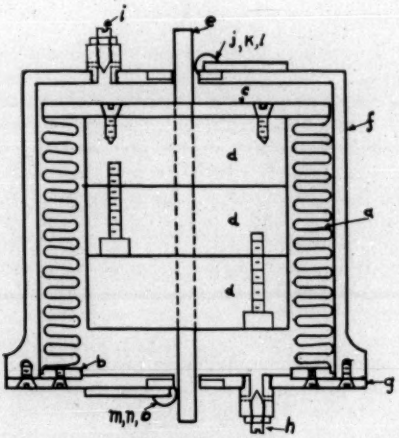

FIG. 1.

Damping is produced by forcing air out of the bellows and by drawing air into the cup during compression and by drawing air into the bellows and by forcing air out of the cup during expansion. By adjusting the needle valves the flow of air may be regulated to produce the desired damping action. If the valves are closed the only escape of air is through the clearance openings about the central rod. When the valves are closed, air is forced out and drawn in slowly and large damping action takes place. However, when the valves are wide open the air is forced out freely from the bellows and drawn freely into the cup and small damping action takes place. If, however, the valves are adjusted between these two extremes they may be set so as to produce an optimum damping effect. It is seen that by using the enclosing cup a double damping action takes place.

While air does not produce a damping proportional to the velocity, it is generally conceded to be quite satisfactory as a means of damping. Furthermore, the viscosity of the air on which damping depends is independent of changes in pressure and varies only with the square root of the Absolute temperature. If the changes in temperature are not large the variation of damping with the Absolute temperature is not excessive.

During the earlier stages of development of the bellows accelerometer a serious limitation in the use of the bellows was observed. The earlier tests showed that the deflection of the bellows was not proportional to the acceleration but fell off as the acceleration increased. The tests also showed that as the accelerations were decreased from higher values to lower the deflections did not decrease in the same proportion. In other words the elastic properties not only did not conform to Hooke's law but also showed a "hysteresis" effect.

Upon further investigation of the bellows it was noticed that upon compression and expansion of the bellows a crackling noise in the bellows was heard. This fact, coupled with the knowledge that the bellows was spun or subjected to high hydrostatic pressure during manufacture, led one to believe that the noises in the bellows might be due to irregular strains which had not been released during manufacture. It was therefore decided to give the bellows a heat treatment and to determine the effect of this treatment on the elastic properties of the bellows.

For this purpose a bellows which had been formed by spinning was chosen for test. Before heat treatment the bellows was tested by applying increasing and then decreasing loads and observing the deflections by an optical lever. These results are shown in Fig. 2, curves (1) and (2). It is noted that neither curve is a straight line and that curve (2) for decreasing loads falls above curve (1) for increasing loads. This indicates poor elastic properties and "hysteresis" in the material.

The bellows was then subjected to a heat treatment. The results of tests after heat treatment are shown in curve (3). The results for increasing and decreasing loads are shown by a common curve which is a straight line up to a load of about 700 gm. which is the limiting load set by the manufacturer. No "hysteresis" effect is noted. The bellows was then given a second heat treatment in the same manner as the first and the test was repeated. Curve (4) shows the results of the second heat treatment. The same linearity persists over the range of loads up to 700 gm. Deflections for corresponding loads are smaller. It is observed that heat treatment in addition to relieving irregular stresses in the bellows increased the stiffness. Since these heat treatments improved the elastic properties of the bellows to such an extent that they could be relied upon, no further heat treatments were given.

Since sylphon bellows may be secured in a wide variety of diameters, lengths, and thicknesses of material, it is possible to design a bellows accelerometer element for a desired frequency and sensitivity. This is done by choosing a bellows of suitable "spring constant" and incorporating in it the proper mass. The calculated frequency and

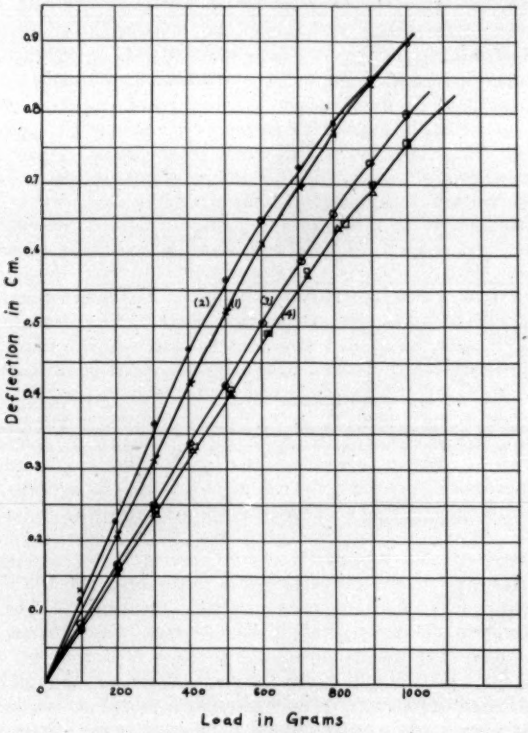

FIG. 2.

sensitivity agree very closely with the observed frequency and sensitivity of the completed element.

In the complete design of an accelerometer it is necessary to make a choice of assembly for the element and to provide a suitable method for making a record. These choices largely depend upon the particular use to which the accelerometer is to be put.

If it is desirable that the recording of accelerations be made at another point than that at which they occur, this may be accomplished by converting the motions of the bellows element into electrical impulses which may be transmitted to the point directly or after amplification. Two obvious methods for electrical operation are by photoelectric currents and by induced currents in a coil in a neighboring magnetic field. The photoelectric method has been developed by the writer and has been found to operate quite satisfactorily. Due to lack of time the inductive effect has so far not been completed though the method of application is quite simple to those conversant with methods of radio amplification. If the instrument is to be made for recording accelerations of small magnitude and high frequency, a mechanical amplification with a photographic recording device is suitable. If for larger magnitude and lower frequency, a chart recording device is convenient. Both of the two latter forms have been developed and will be described.

For a photographic recording type of Bellows accelerometer the element already described was mounted in a portable aluminum case shown in Fig. 3. This instrument was provided with a 6-volt motor-driven film holder carrying about 35 feet of 70 mm. motion picture film. The element (A) was provided with means for measuring the motion of the mass during acceleration and recording it photographically. For this purpose a spindle (a) carrying a small concave mirror was mounted above the axial rod (b) and a double loop of phosphor bronze ribbon (c) was attached to the rod and was passed around the spindle and extended to the spiral spring (d) attached to the support (e).

During acceleration the ribbon actuated the spindle and its mirror and a beam of light from a lamp (f) falling upon the mirror was deflected through a slit at the top of the case into a film holder (g) where the deflections were recorded on a moving photographic film.

By controlling the factors determining the sensitivity of the element and by making the spindle of small radius and the length of the beam from the mirror to the film large, the sensitivity of this form of accelerometer may be made quite great.

Before using the bellows element in a photographic recording form the element was subjected to rigid tests for elastic response of the bellows and for freedom from friction in the miniature bearings. For the purpose of test the element was mounted with the axial rod in the horizontal position so that the mass inside of the bellows would be carried on the bearings. A compressional force on the bellows was applied by applying the tension of a calibrated spiral spring at one end of the bellows. The observation for compression was made by projecting a beam of light upon a mirror carried by the spindle and from there to a scale where its deflection was observed visually. The de-

flections of the bellows for the loads in grams both for increasing and decreasing loads are shown in Fig. 4. The curve is a straight line and shows no hysteresis effect, the deflections for decreasing loads being the same as those for increasing loads. No effect of friction in the bearings

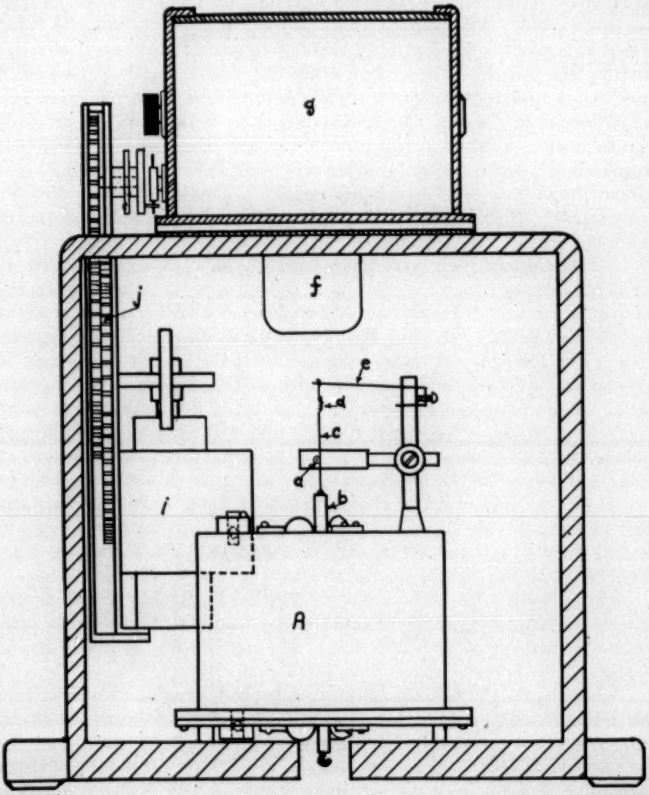

FIG. 3.

was observed. The deflections for any particular load instantly assumed a particular value which was not affected by subsequent tapping of the element. Tests showed that deflections versus loads were as constant for the element in the horizontal position as for the vertical

position indicating that any friction introduced by the miniature bearings was negligible.

A chart recording type of Bellows accelerometer is shown in Fig. 5. In this photograph the central rod (e) of the bellows element is shown extending upward, the upper end being provided with a rack which engages a pinion of very fine, accurately cut teeth. The pinion is

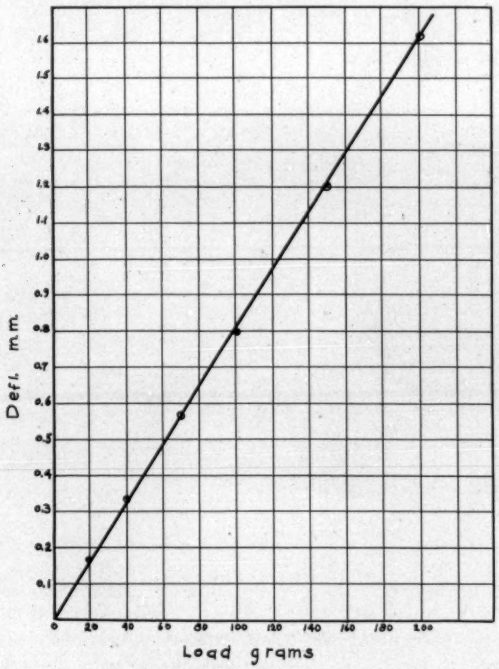

FIG. 4.

carried by a pivoted axle carried by the support (o). To the pinion is attached a stylus (s) which bears against a waxed chart carried on a drum (d). The drum is driven by a clock motor whose speed is controlled between wide limits both by change gears and by regulation of a governor. The roll of waxed paper (p) is carried on an upright post in such a position that it readily unrolls from the spool and rewinds upon the drum. Ordinarily only a few turns of paper about the drum

will be required in making a record and these few turns on the drum will not appreciably change the speed of recording. The waxed paper is readily removed after a record is made.

To enable the record of acceleration to be read directly, a multiplicity of stationary styluses was mounted on a post (r) parallel to the drum and each stylus is adjusted to a scale calibrated in known values of "g." The support carrying these styluses is adjusted so that each stylus presses against the waxed paper and leaves its trace. Thus the calibration appears as parallel markings on the chart together with the record of acceleration.

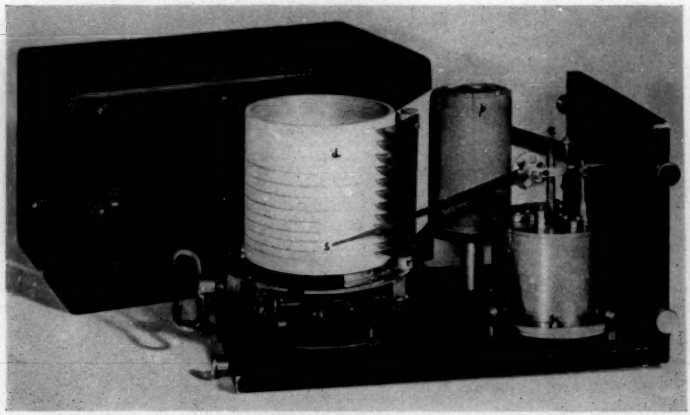

FIG. 5.

For the purpose of testing the Bellows accelerometer a hook was screwed into the lower end of the axial rod which extends through the bellows. The instrument was then supported vertically and weights were attached to the hook. Deflections of the pointer were observed for various loads up to about 2,500 gms. The curve obtained by plotting these values of loads against deflections is shown in Fig. 6. The curve is not quite a straight line due to the shortness of the pointer. The points for decreasing loads falls upon the same curve as that for increasing loads. That friction due to the stylus against the chart is negligible is shown by the fact that each deflection at once reaches its full value and the stylus again returns to the starting point when the load is removed.

Fig. 7 is a calibration curve obtained by placing the instrument in

a horizontal position and whirling it on a whirling table. The deflections of the pointer in centimeters against accelerations in "g" forms practically a straight line except for the larger values of deflections where the straight line linearity falls off due to the larger angular deflection of the comparatively short pointer.

As a check on the calibration curve and as an aid in future calibrations of the instrument when the zero of the pointer might be adjusted to a different position on the scale a further test was made. The instrument was placed in a vertical position in which position the pointer

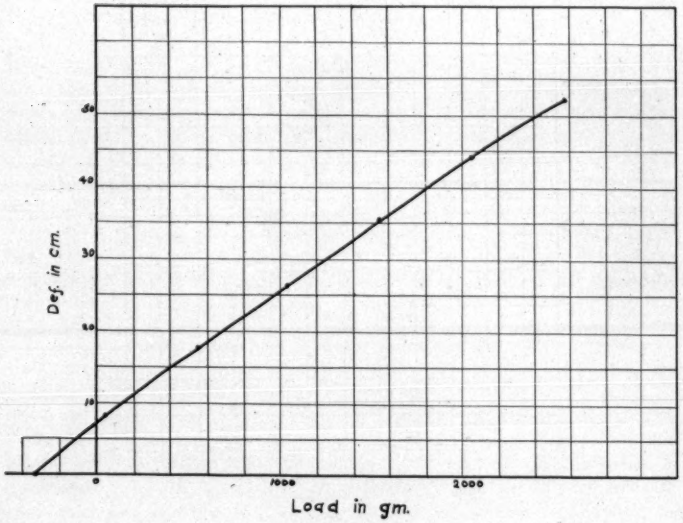

FIG. 6.

indicated 1 "g." A hook was then attached to the lower end of the axial rod (e) and a load was attached and increased until a deflection was produced for a given value of "g" as indicated on the calibration curve. This load divided by the difference in the values of "g" would give the load to produce 1 "g." This increment of load checked as closely as observations could be made with the weight of the masses attached to the rod inside of the bellows. Hence to recalibrate the instrument in case it should be desirable to shift the zero of the pointer all that has to be done is to determine the deflections for these increments of loads for the different values of "g."

It is quite obvious that to avoid excessive friction of the stylus against the drum, its pressure should be adjusted to as small a value as possible such that a good trace will be made.

While the bellows accelerometer here described measures only one component of acceleration, it can be readily modified to incorporate two elements at right angles to each other so that two components may be recorded on the same chart.

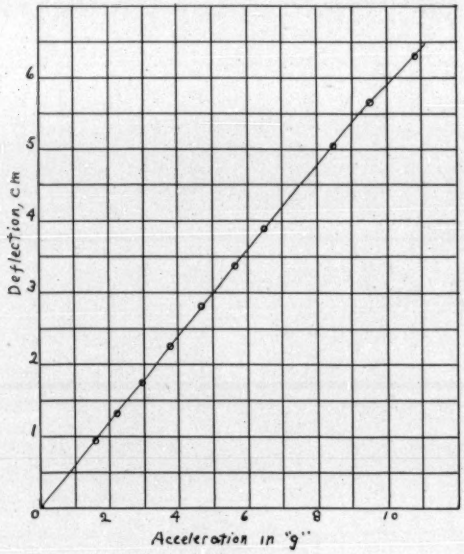

FIG. 7.

For recording a single component of acceleration in a given direction the instrument is mounted either on a vertical or horizontal base in the desired direction.

The accelerometer is provided with a readily removable cover provided with a transparent window so that the instrument is easily adjusted and the record may be observed while a test is being made.

V.2
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REBUILDING AMERICA'S PRIMARY WEALTH—THE SOIL.

BY

MORRIS LLEWELLYN COOKE.

Eastern Pennsylvania—including the watersheds of the Delaware, the Schuylkill, and the Susquehanna, on which much of the prosperity of Philadelphia depends—is gradually but inevitably being impoverished and ruined through the wastage of its soils.

Erosion of soil shows itself most obviously in the form of gnawing gullies, and on an aerial map of a farm down in east-central Alabama one can count more than a thousand gullies.[1] Pennsylvania soils, however, suffer mostly from what is known as sheet erosion—an insidious deterioration which spreads more or less evenly, and therefore practically unnoticed, over an entire area. Only within the last ten or fifteen years have measures been devised which give promise of being able to cope successfully with this situation, but their application in Pennsylvania has hardly begun. Even in some of those parts of the country where in the last few years soil conservation practices have been most widely installed, it can hardly be claimed that we are more than holding our own.

SOIL EROSION IN NORTH AMERICA.

Some three hundred years ago, North America was the richest continent on earth from the standpoint of natural resources. Today, if we have not already lost that enviable position, we are dangerously close to doing so. The courageous, pioneering men and women who moved relentlessly westward from the thirteen original States conquered this continent and built, within an amazingly short time as history is reckoned, the greatest industrial empire in the world.

The conquest of the continent was unquestionably necessary. It was part of the inevitable march of civilization. But it was not accomplished without cost. We have made great drains on our wealth of coal and oil. We have cleared away millions of acres of virgin forest. And we have been guilty of an incredible exploitation of our most essential and primary natural wealth—our irreplaceable soil. Today we find ourselves in the position of the man who suddenly awakes to the fact that he has squandered millions, and whose bank book shows he has only a few thousands left.

This careening exploitation must stop—and stop very soon—if we are to continue in our place as one of the leading nations of the world.

[1] H. H. Bennett, "Soil Conservation," p. 605, New York, 1939.

The first step in stopping this waste is to slow down the rate. Having once applied the brakes, we can eventually count on turning the corner safely, and begin steadily and diligently the imperative business of rebuilding.

Why do we need to rebuild? We need to rebuild because already half of all the land in the United States has been damaged. The cold, physical facts are that we have allowed erosion to ruin some 282 million acres—chiefly crop and grazing land.

Considering cropland alone, we must face the fact that about fifty million acres of once-productive land has been ruined for any further immediate cultivation, for it takes several hundred years to create one inch of topsoil. Another fifty million acres of cropland is in almost as bad condition. Another hundred million acres of food and fibre producing land has lost from a fourth to three-fourths of its fertile topsoil. And on still another hundred million acres of cropland the destructive erosion process is under way.

Three hundred million acres ruined, damaged, and in process of impoverishment! Like a cancer in the side of our country, this erosion evil has been permitted to grow unmolested until recent years, despite warnings of some of our early leaders as far back as Washington and Jefferson.

It was not until 1929 that we took the first major step away from exploitation and in the direction of conservation. In that year Congress adopted an amendment to the Agricultural Appropriation Bill for the fiscal year 1930, approved February 16, 1929,[2] which provided for the establishment of soil erosion experiment stations in the major agricultural regions of the country where erosion was known to be a serious problem.[3] The first of these stations was established at Guthrie, Oklahoma, and shortly thereafter a total of ten stations were studying the causes and control of erosion in different parts of the nation.

The work of these experiment stations not only confirmed the seriousness of the soil erosion problem; it showed that erosion was even more serious and widespread than most people had imagined. The work also pointed out avenues for control of erosion.

The seriousness of the situation made action on a nation-wide scale imperative. In September, 1933 the Soil Erosion Service was established in the Department of the Interior for the purpose of demonstrating the practical possibilities of soil erosion control. To this end a number of demonstration projects were set up in various erosion problem areas of the country, where farmers could inspect practical erosion control practices in operation under the best of everyday farming conditions.

In 1935 the Soil Erosion Service was transferred to the Department

[2] Public No. 769, 70th Congress.

[3] H. H. Bennett, "The National Program of Soil and Water Conservation," *Jour. Am. Soc. Agronomy*, May, 1931.

of Agriculture, and by Act of Congress [4] became the Soil Conservation Service. Since that date the Service has been the spearhead of the soil conservation movement across the nation with crop specialists, agricultural engineers, land scientists, biologists, hydrologists, foresters, and others working out on the land cooperatively with farmers in the now quite generally approved effort to maintain and build back our soil wealth.

In this program, two policies that have been adhered to from the beginning with great success are: (1) recognition that each acre must be treated according to its individual needs and adaptabilities; and (2) work must be carried on by and with farmers, out on their land where the erosion problems actually exist, rather than around conference tables wholly separated from the soil.

The voluntary organization of soil conservation districts by farmers in forty-two States has been a motivating force in getting an increasingly widespread application of soil conservation practices. In the forty-four States where the necessary enabling legislation has been enacted, farmers can petition their State Governments for conservation districts where and when they feel that group action is the best method of solving local erosion problems. By the democratic processes of the majority will, as expressed in the referendum vote, and the majority rule through their elected supervisors, the farmers organize and operate their own soil conservation districts. The Soil Conservation Service offers technical assistance to districts as well as the use of equipment, if the facilities are available and the districts request such help with their conservation work.

The conservation district movement has grown steadily since its inception nearly six years ago.[5] Latest figures show a total of 881 districts, comprising over half a billion acres in the 2,432,000 farms now within district boundaries. An example of the growth of the movement was revealed during a four weeks' period this spring (1943) when 5,000 farms, including better than two million acres, were added to the districts by the vote of the farmers.

Conservation plans have been made for sixty-six million acres and have been carried out to completion on forty million of these acres. Partial plans are now being put into effect on another twenty-four million acres as part of an intensified wartime effort to achieve the widest possible application of conservation practices designed to help farmers meet wartime production demands. Early reports show that thousands and thousands of farmers have adopted at least one conservation farming practice for the first time this year as an aid to greater food production.

[4] Public No. 46, 74th Congress, approved April 27, 1935.

[5] The first soil conservation district—the Brown Creek District, North Carolina—was established August 4, 1937.

CROP YIELDS INCREASED.

The work of the Soil Conservation Service is resulting in far more than the saving of natural resources. It is bringing about increased yields per acre of crops that are vitally important to the war effort. The increased production is also bringing new sources of income and food to farm families. The manifold benefits of conservation farming have been proved beyond any doubt. Results from experiment station test plots and from thousands of representative farms throughout the nation establish this point. The increased yields per acre average at least twenty per cent., which means that if conservation practices were applied on all the present farm lands in the United States, the increased production probably would be equivalent to a sixth farm for every five farms now in operation. Furthermore, the results over a period of years indicate that the increased yields can be sustained on those acres where the moisture is conserved and the soil is used and tilled according to its proper capability.

Almost invariably, where the supply of feed crops has been increased through conservation farming, the farmers also have new sources of income and food from their new or enlarged livestock and poultry enterprises. Conservation farming lays the foundation for a diversification of farming in contrast to the older, exhausting system of one cash crop year after year.

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Increased per-acre yields are even more important now, in wartime, because the greater production achieved through conservation practices is gained at no additional cost—and in many cases with as much as 10 per cent. less time, 20 per cent. less fuel, and with less labor and wear on equipment.

Looking ahead to the day when the United Nations are victorious, we shall find a hungry world wanting and needing even greater supplies of food. In the great post-war rehabilitation effort to restore peace, health, and industry to the world, American agriculture will certainly be called on to play a large role.

Reports on conservation work on 1,829 farms done in soil conservation districts in the nine Southeastern States show that the use of conservation practices in the production of five of the major regional crops resulted in per-acre yield increases ranging from 19 to 42 per cent., and farm production increases ranging from 6 to 110 per cent.

In the case of corn, 14,000 fewer acres were planted, but 178,000 bushels more were produced through the increased per-acre yields due to conservation practices.

In this connection Bennett [6] says:

[6] "War and Postwar Food Production." Address, The Citizens Conference on Planning, American Planning and Civic Association, Omaha, Nebraska, June 14, 1943. (Mimeographed) by H. H. Bennett.

"And there was increased diversification of crops—widespread diversification, such as I have heard recommended all my life but never saw put into effect until the building process of good land use and soil conservation got in powerful strokes for husbandry and better income. The income on these farms, by the way, was increased on the average by $860.32 per farm.

"Let me give another illustration of how soil conservation aids production. I have in mind 12 million acres of wet lands that were brought back into crop-production service, or had the yields increased, through drainage operations carried out by 40 CCC camps assigned to the Soil Conservation Service for work in drainage districts. Ditches were cleared of silt, obstructive growths of brush were removed, new outlets were opened—and, as a result, excess water was removed from 12 million acres of otherwise good farm land. These lands are now making a contribution of very large proportions to our food-production program.

"The job of rehabilitation and improvement in this instance included the cleaning out of 6,444 miles of ditches, involving the removal of 64 million cubic yards of silt—mainly eroded soil deposited in the ditches. It included, also, cutting out obstructive vegetation from almost 11,000 miles of ditches, the rehabilitation of 340 miles of main outlet tile drains, and the leveling off of more than 3,000 miles of obstructive spoilbank material.

"Farmers contributed $4,627,855, mainly in cash, to the cost of these operations and much more in the way of work on lateral ditches and the lesser tile drains. The lands benefited extend far back from the ditches along which the principal heavy work was done. Anyone who fails to see how this single item of conservation work is now helping win the war, might also fail to see the tremendous part the nation-wide soil conservation program is contributing—and can further contribute—to our war production effort.

"Look a little closer at those 12 million acres of high grade land benefited by drainage. If only 40 percent of the benefited area were planted to corn, undoubtedly there would be an increased yield of at least 10 bushels per acre—most likely 30 bushels per acre. A ten bushel increase per acre would mean about 50 million bushels more of corn, which, if converted into pork, would produce 2,500,000 two-hundred-pound hogs or 500,000,000 pounds of live pork. And still there would be 7 million acres more for increased yields and new plantings of soybeans, pasture, hay, and other crops.

"These improved lands are in production now.

"We have in this country some 30 million acres more of imperfectly drained land—much the same kind as that I have referred to. . . . Most of this land could be benefited precisely as the 12 million acres already have been benefited. We know where the land is and what can be done with it, if given the facilities—mainly 'draglines' for moving earth."

At the soil and water conservation experiment station, near Clarinda, in southwestern Iowa, on an 8-per cent. slope of the principal type of agricultural land in the Missouri Valley upland, corn planted on the contour averaged, over a period of six years, 30 bushels to the acre, in comparison with only 18 bushels per acre where the rows ran up and down the slope. The two fields were on the same kind of land on the

same farm, and they were planted at the same time and cultivated in precisely the same manner, except for row direction.

REDUCTION OF SILTATION.

And by tying down the soil resource in the farmers' fields we can expect to be rewarded in other ways beyond the substantial, long-time benefits in the way of increased production of food that is certain to come from crop-lands kept productive with common sense conservation farming.

When the topsoil is properly guarded against erosion there is less damage to reservoirs and streams, because the silt that fills up water basins and muddies natural drainageways comes from the lands of the watershed area. The increasing silt load each year is causing more and more damage to Philadelphia's "manufactured" water supply. The story is the same all over the country. The Soil Conservation Service has made surveys which show that erosion and subsequent silting are a distinct menace to the nation. For instance, if erosion is permitted to go uncontrolled on the watersheds, the useful life of more than 20 per cent. of the water supply reservoirs of the United States will be reduced to less than 50 years. And another 25 per cent. of our reservoirs will be rendered virtually worthless for water supply in from 50 to 100 years because they will be filled with lost soil that should be producing food and fibre crops in the fields.[7]

It takes only simple reasoning to realize that topsoil kept on the farms where it belongs means keeping it out of reservoirs where it occupies space intended for water storage. Moreover, the Soil Conservation Service has evidence to prove that silt can be kept out of reservoirs. An outstanding example of this work is at High Point, North Carolina, where ten years ago the city reservoir was silting badly due to erosion on farm lands in the drainage area upstream. Erosion control practices were applied to something over half of these farm lands which had been supplying the costly sediment. In less than a decade of conservation practices on this watershed the rate of silting has been reduced by a fourth.[8]

PROTECTIVE VALUE OF SURFACE COVER.

Experimental tests show that the terminal velocity of raindrops is controlled not so much by the distance of fall as by the nature of the growing crops or cover on the land. In other words, the effects of the impact of raindrops the instant they strike the earth means much in the control of soil erosion. The amount of crop stubble or the vegetative material over the field on which the rain falls will largely determine how

[7] "The Control of Reservoir Silting," U. S. Dept. of Agriculture Misc. Pub. 521, Soil Conservation Service (in galley proof), Carl B. Brown, 1943.

[8] Idem.

much of the topsoil will be carried away by the runoff water. And, too, methods of cultivation that control the rate and speed of runoff of water from the land are highly important in cutting down soil erosion and in getting maximum use of the moisture for added crop growth and bigger yields.

Silting of reservoirs also adds to the problems of city health departments. Silt that pours into water supply reservoirs usually contains bacteria and other material not conducive to human health. Such water must be purified before it is fit for human consumption. Chlorine normally is used to accomplish this. However, purification of water is not a simple process and there seems to be some doubt as to the amount of chlorine that can be used safely in water supplies before the dosage becomes an injurious factor.

Whether or not the enormous chlorine dosage, used in some reservoirs to neutralize the bacteria carried in silt, may be a contributing cause to stomach ulcers, digestive disorders, and other troubles of the human system is an unanswered question. The solution, however, may lie in reducing the silt intake of reservoirs so that the necessity for such large chlorine doses will be similarly reduced. And to reduce the silt intake of reservoirs, we must apply conservation farming designed to hold the soil in fields and forested areas of the watersheds; thus, cutting the amount of erosional material washing downstream.

Also, increased quantities of silt entering reservoirs from unprotected farm lands often involve added cost for precipitation of silt by the alum process, as used in Philadelphia. Brown [9] says:

"Another damage by sediment is represented in the cost of filtering a water supply. Although this is distinct from the problem of reservoir silting, it should be recognized that many forms of silting control may be expected to decrease the cost of water treatment. Garin and Forster found that the average cost of water treatment in 22 North Carolina Piedmont cities, including overhead charges and amortization of plants and equipment, is about $70 per million gallons. For treatment alone, the cost is $27, of which $5 is for the cost of chemicals, primarily alum used for flocculation. . . . Garin and Forster estimated that a 30-percent reduction in the suspended load of the streams, a modest expectation from an adequate erosion-control program, would result in an average saving of $1.50 per million gallons in the cost of treatment. They concluded that other savings resulting from smaller capital outlay for new settling basins and filter plants and from reduced costs of flushing and other plant operations would eventually bring the total savings to $7 per million gallons, or $94,500 annually for these 22 cities. Capitalized at 5 percent, the present value of a 30 percent smaller sediment load in water purification alone would be $1,890,000."

In terms of the taxpayers' dollars, the immediate and long-time advantages of soil conservation are apparent. It is logical and good

[9] Idem.

business to eliminate, virtually for all time, the original causes of silting and pollution rather than to be confronted at periodic intervals with bills for costly dredging and cleaning operations. While the farmer protects his basic soil resource for sustained production of crops, the interests of those in the cities depending on reservoirs for drinking water are being protected simultaneously. The farmer maintains the productive capacity of his land to pay his share of the taxes, and the elimination of unnecessary rehabilitation work in reservoirs cuts the cost of maintaining city water supplies.

But still other damages follow in the wake of soil erosion. Pools created for hydro-electric development gradually fill up. Some have filled to the top of the dam before a wheel turned. And irrigation reservoirs and canals and drainage ditches are being depleted by the process. Silt is injurious to fish in many streams, and siltage is damaging to the oyster industry. Eroded lands, reduced yields, and abandonment of land, reservoirs, and drainage ditches caused by erosion also have deleterious effects in terms of reduced purchasing power and its consequent effect on the marketing and sale of manufactured articles, reduced social and economic opportunities, and malnutrition.

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COST OF EROSION.

The approximate costs of soil erosion to the nation, direct and indirect, are shown in the estimated annual damages below:[10]

Croplands, pastures—soil removal, washing out of seed and fertilizer, covering lowlands with eroded soil	$400,000,000	Sedimentation, irrigation ditches	$ 18,000,000
Highways	180,000,000	Sedimentation, drainage ditches	15,000,000
Railways	100,000,000	Sediments, streambank erosion, etc. (within urban areas)	25,000,000
Sedimentation, reservoirs	30,000,000	Flood damage	42,000,000
Sedimentation, navigable streams and harbors	29,000,000	Wildlife, fish, oysters, etc.	5,000,000
		Soil loss	3,000,000,000
Total Cost	$3,844,000,000		

For the three billion tons of soil lost annually through the waste of erosion, we can assess against ourselves as a nation an accumulating charge of three billion dollars as a yearly minimum for the permanent loss of available and potential plant food constituents, and for reducing by soil removal the limited depth of productive soil material. There is no easy way, however, of estimating the full value of productive land that should be used as a continuing dependable source of livelihood for men, women, and children.

It always pays to use land according to its capability and to grow the

[10] H. H. Bennett, and W. C. Pryor, "This Land We Defend," pp. 35, 36, New York, 1942. And other estimates from the Soil Conservation Service.

crops or grass or trees for which the particular type of land is best suited. Even now, in the midst of the worst of all wars, it is better to plant trees or grass on steep, eroded slopes than to waste precious manpower and fertilizer trying to grow cotton, corn, or any other row crop on such unfavorable land. When attempts are made to cultivate either hopelessly eroded or highly erodible fields, we lose time and money as well as soil in the futile effort.

Wise development and use of the land is as much a phase of conservation farming as, for instance, contour cultivation or terraces. Proper development and management of pasture and range areas for grazing of ivestock; growing of legumes and grasses for hay, soil-building, and seed; and the correct use of wooded areas on a sustained yield basis—all of these are vital parts of the over-all, complete conservation farming movement that is spreading across America.

SOIL CONSERVATION IS MORE THAN SAVING SOIL.

Conservation farming adds up to more than merely saving the soil from erosion and exhaustion, or storing and using all available moisture, or re-forestation and management of wooded areas, or re-seeding and properly grazing pastures and range. It is a new way of American agriculture and it is bringing a better way of life—economically, industrially, and socially—to millions of farm families. Conservation farming is a revolutionary change in agriculture that may well go down in the annals of history alongside other progressive world movements, including the industrial revolution. No doubt the practices of conservation farming should have been used long ago in this and other countries, but it took a desperate necessity to awaken and arouse us to the urgent need of a better way of farming. Dust storms, a new phenomena in America a decade ago, and now global war, on a scale greater and more disastrous than any in world history, have been instrumental in bringing about and speeding up the movement of soil saving and better farming. The spreading of the conservation movement across American farm lands gives promise of untold benefits to be derived in future years.

The rewards of conservation farming in terms of greater per-acre yields are a known quantity—an average of at least a fifth more crops. If extended to the large area of adaptable lands throughout the world, this revolutionary system of farming promises an ultimate realization of freedom from want for everyone everywhere. And this alone will minimize the danger of future international misunderstandings leading to another war, which could conceivably destroy modern civilization. For as man builds greater flying machines he must also establish deeper roots in the soil, if the human race is to be protected from utter self-annihilation in coming years.

America can give to the world a new attitude about man's primary

wealth.[11] Rather than continuously coveting a neighbor's land and attempting to take it by force, men of all nations must accept a new way of living for their very survival. This new way of life must have a common foundation upon which to reconstruct the post-war world. Mutual concern over the soil's productive capacity should offer a realistic and practical anchor for a weary and hungry world. Cooperating together, working with the good earth, men can reap a bountiful harvest of abundance year after year. Right living with the soil can also benefit men through reducing, if not virtually eliminating the problem of siltation and the more disastrous floods; lessening drought dangers; and curtailing other catastrophes, which periodically jolt a world busy at exploitation of one kind or another. The streams, too, will run clearer and the air will be cleaner and healthier when we put forth our best efforts toward keeping the soil on the earth's surface, where nature placed it for our sustenance.

Critical as they will be, the post-war years nevertheless will offer an untold opportunity for man to learn how to live and to work with his neighbors for the good of all concerned. And when we learn this lesson well, service to country can lie in protecting the soil rather than in defending the land. Wise husbandry of the soil resource, including proper use of the plowshare, will go far toward outmoding the sword as an implement of man's way of survival in the years ahead.

[11] See "On Total Conservation" introductory remarks by Morris Llewellyn Cooke at a symposium on "The Administrative Task of Conservation—Public and Private" at Bicentennial of University of Pennsylvania.

A QUANTITATIVE STUDY OF ISOBARIC EQUILIBRIUM AND GRAVITY ANOMALIES IN THE HAWAIIAN ISLANDS.

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ABSTRACT.

The deformation of a strong elastic lithosphere supported by an underlying weak magma is calculated for a long mountainous load. The deformations produce vertical superposed stresses in the lithosphere that contribute to the support of the mountain and distribute its weight over a large area. Employing the principle of isobaric equilibrium, the distribution of the vertical supporting stress and the associated gravity anomalies may be determined by analysis.

The results of the analysis are applied to the Hawaiian chain and it is shown that the calculated physical properties and gravity anomalies are remarkably like those observed. It is inferred from the study that: (*a*) a strong lithosphere underlies the Hawaiians and this section is practically identical with those underlying other regions; (*b*) the lithosphere will support one-sided stresses approximating 10^9 dynes/cm.^{2} for long periods of time; (*c*) the distribution of gravity anomaly may be described quantitatively in terms of the calculated deformations; (*d*) the principle of isobaric equilibrium is obeyed throughout the region whereas the isostatic principle is generally violated; and (*e*) the distribution of compensating masses is not at all like that demanded by the principle of isostasy.

It is concluded that isostasy leads to results that are clearly wrong when applied to mountains or other deformed regions. The principle of isobaric equilibrium appears, however, to be well established by the investigation.

Contemporary ideas concerning the equilibrium of the earth's surface are embodied in the principle of isostasy. This principle has gained wide recognition and has influenced the interpretation of geological phenomena for several decades. Wm. Bowie [1] writes: "According to the principle of isostasy, if the earth's crust were cut into prisms of the same cross-section by imaginary vertical planes, the prisms would have the same mass if the isostatic conditions were perfect." Although isostasy prevails over most of the undeformed regions of the earth, it has become apparent in recent years that it definitely fails to describe the observed equilibrium near mountains, continental boundaries, volcanic islands or ocean deeps.

In a recent paper [2] a quantitative investigation was made of the influence of a strong lithosphere on departures from isostasy. It was shown that isostasy is a special case of a more general principle called, for convenience, the principle of isobaric equilibrium. This most useful principle was formulated because it was recognized that the lithosphere

[1] Wm. Bowie, Bull. No. 78, National Research Council, p. 102.

[2] Ross Gunn, JOURNAL OF THE FRANKLIN INSTITUTE, 236, 47, No. 1, July 1943.

has a finite strength and that vertical stresses existing therein due to a superposed load will modify the distribution of the stresses passed on to the underlying magma. The extended principle is a criterion for the vertical equilibrium of the lithosphere even in deformed regions of the earth and may be written

$$p = M\bar{g} + S_v = \text{constant}, \tag{1}$$

where p is the pressure on some selected gravitational equipotential surface within the weak magma underlying the lithosphere, M is the mass per unit area of the material above the selected equipotential or isobaric surface, $\bar{g}$ is the mean acceleration due to gravity in the region, and S_v is the superposed vertical stress provided by the finite strength and deformation of the lithosphere. The pressure p so defined is a constant over the surface of the earth provided it is everywhere in equilibrium.

The superposed vertical stress S_v is the space rate of change of the shear force acting on the lithosphere considered as an elastically supported beam of unit width. Thus, provided the deformation of the lithosphere can be calculated for any arbitrary superposed distribution of load, it is possible by aid of elastic beam theory to determine the distribution of vertical stress and shear therein. The superposed vertical stress function has been shown to be [2]

$$S_v = y(d_0 - w)g - W, \tag{2}$$

where y is the vertical deformation of the neutral axis of the continuous lithospheric beam, d_0 the density of the underlying weak magma, w is the density of the fluid in which the deformation may be immersed, and W is the superposed load per unit area at the same point where y and S_v are evaluated. It is evident that the deformed figures of the neutral axis and the surface will be practically identical and may be used interchangeably. Also it is clear that both Eqs. (1) and (2) reduce to statements describing isostasy provided S_v approaches zero.

In passing, it is recognized that transient, non-equilibrium states are possible in which the difference in pressure Δp along an equipotential surface may have the form

$$\Delta p = p_0 \exp(-t/T),$$

where p_0 is the original pressure difference when the time t is zero. This pressure difference is mostly equalized by the horizontal transfer of liquid magma in a time, T, called the relaxation time. Data from the warping of Fennoscandia suggest that T is approximately 25,000 years. Therefore, the transient term may be ignored in the majority of geological investigations.

In order to determine the vertical deformation of the lithosphere, it is necessary to investigate the properties of elastic beams so supported

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that the restoring force due to a given deformation is proportional to the deformation. Such an investigation was made in a companion paper.[2] It was shown that if very long blocks of sediments of various widths were superposed on the lithosphere, then for them to be in substantial isostatic equilibrium, they must be at least 330 kilometers wide. It was found that the lithosphere carried 81 per cent. of the load due to a block only 50 kilometers wide. It thus appears that the principle of isostasy as usually applied to mountainous areas is incomplete and not in accord with the physical facts. Actually, it is found that the most of such loads on the lithosphere are not completely compensated locally but a calculable part of the compensation is immediately under the load and another part is distributed over the sides to a distance approximating 250 kilometers.

In the present paper the work is extended to a quantitative determination of the deformation of the lithosphere due to a loading that closely approximates that of a long linear mountain range having any arbitrary slope and height. This analysis is then applied to the Hawaiian range.

THE DEFORMED FIGURE OF A LITHOSPHERE BEARING A MOUNTAIN CHAIN.

Consider a section of the uniform elastic lithosphere resting on a weak magma that supports it hydrostatically. Assume that the section is of unit width, effective thickness T, and that its uniform elastic modulus is E. The restoring stress σ due to a downward displacement y of the underlying magma by Eq. (10) of the author's first paper [2] is

$$\sigma = (d_0 - w)gy, \tag{3}$$

where d_0 is the density of the underlying magma and w is the density of any sediments or fluid that may completely fill the resulting depressions. Such a restoring stress acting on a beam carrying a superposed applied load Wdx will cause the beam to be deflected downward a distance

$$dy = \frac{Wbe^{-bx}}{2(d_0 - w)g}(\cos bx + \sin bx)dx, \tag{4}$$

where W is the superposed load per unit area or the load stress and b is a fundamental constant of the lithosphere that may be directly determined from observation as in reference 2 where it was found that $b = 8.4 \cdot 10^{-8}$ cm.$^{-1}$. Or it may be calculated from the relation

$$b^4 = \frac{3(d_0 - w)g}{ET^3}. \tag{5}$$

These equations follow immediately from Eqs. (14) and (15) of the author's first paper on this subject.[2] In Eq. (4), x is the horizontal distance between the applied elementary load Wdx and the point at

which dy is evaluated. Now if the distribution of the applied load is known as a function of x, it is clear that the value of y may be determined by Eq. (4) for any selected point. Thus, by computing y for successive positions, the figure of the downward deformation of the lithosphere may be determined, and from this by aid of the stress function, Eq. (2), the stress distribution and gravity defect may be evaluated.

One of the important objects of geology is to describe the deformations of the earth's crust near mountain chains. One therefore proceeds to a calculation of the deformation of the lithosphere by a very long symmetrical mountain of density d whose figure in a plane at right angles to the axis of the chain is defined by an equation of the form

$$h = h_0 \epsilon^{-az}, \tag{6}$$

where h_0 is the maximum height and h is the height at a distance z on either side of the axis of symmetry. By suitably selecting h_0 and a, it is possible to describe almost any type of mountain from a sharp peak ("a" large) to a flat plateau ("a" zero). Figure 1 shows such a loga-

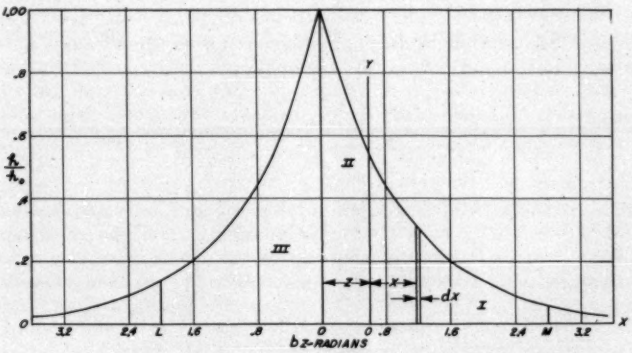

FIG. 1. Cross section of assumed logarithmic mountain.

rithmic mountain. A complicated range may be analyzed by superposing the solutions for a series of such elementary forms. For the elementary mountain described by Eq. (6) one evaluates the downward deformation of the lithosphere at the point o which is taken as the origin for x, while the origin for z is taken at the axis of symmetry. From Fig. 1 it may be seen that $\int dy$ as a function of z and x is determined by the sum of 3 integrals as follows:

$$I = \int_0^\infty \epsilon^{-az} \epsilon^{-(a+b)z} (\cos bx + \sin bx) dx, \tag{7}$$

$$II = \int_0^z \epsilon^{-az}\epsilon^{-(b-a)z}(\cos bx + \sin bx)dx, \tag{8}$$

$$III = \int_z^\infty \epsilon^{+az}\epsilon^{-(a+b)z}(\cos bx + \sin bx)dx. \tag{9}$$

Carrying out the integrations and multiplying by the coefficient of Eq. (4), it is found that the downward deflection of the lithosphere due to a superposed mountain of density d immersed in a fluid of density w and having the assumed figure is

$$y = \frac{h_0(d-w)}{d_0 - w} \cdot F, \tag{10}$$

where

$$F = \frac{1}{1 + \frac{1}{4}\left(\frac{a}{b}\right)^4}\left[\epsilon^{-az} + \left[\frac{1}{4}\left(\frac{a}{b}\right)^3 - \frac{1}{2}\left(\frac{a}{b}\right)\right]\epsilon^{-bz}\cos bz + \left[\frac{1}{4}\left(\frac{a}{b}\right)^3 + \frac{1}{2}\left(\frac{a}{b}\right)\right]\epsilon^{-bz}\sin bz\right]. \tag{11}$$

In most cases the density w of the fluid in which the mountain is submerged is zero, but for mountains resting on the ocean bottom, it is evident that $w = 1.03$ gms./cm.^{3}. If the integration is not carried to infinity but is terminated at $z = +M$ and $z = -L$, then the following expression must be added to Eq. (10):

$$y_2 = \frac{-h_0(d-w)}{4(d_0 - w)\left(1 + \frac{a}{b} + \frac{a^2}{2b^2}\right)} \times \left[\epsilon^{-az}\left[\left(\frac{a}{b} + 2\right)\epsilon^{-(a+b)M}\cos bM - \frac{a}{b}\epsilon^{-(a+b)M}\sin bM\right] + \epsilon^{+az}\left[\left(\frac{a}{b} + 2\right)\epsilon^{-(a+b)L}\cos bL - \frac{a}{b}\epsilon^{-(a+b)L}\sin bL\right]\right]. \tag{12}$$

The reader may verify that Eqs. (10) and (12) reduce to Eq. (18) of reference (2) when $a = 0$.

In Fig. 2 is plotted for reference the form function F for several significant values of a/b. The corresponding figures for the applied mountain load are plotted immediately above. The height of the superposed load is $h_0\epsilon^{-az}$ so that the actual observed height above the original level is this minus the distance the load sinks below the original surface or y. Thus, the actual height is h_a or

$$h_a = h_0\left(\epsilon^{-az} - \frac{d-w}{d_0 - w}F\right). \tag{13}$$

This expression may be used to determine h_0 from the observed figure of a given mountain range.

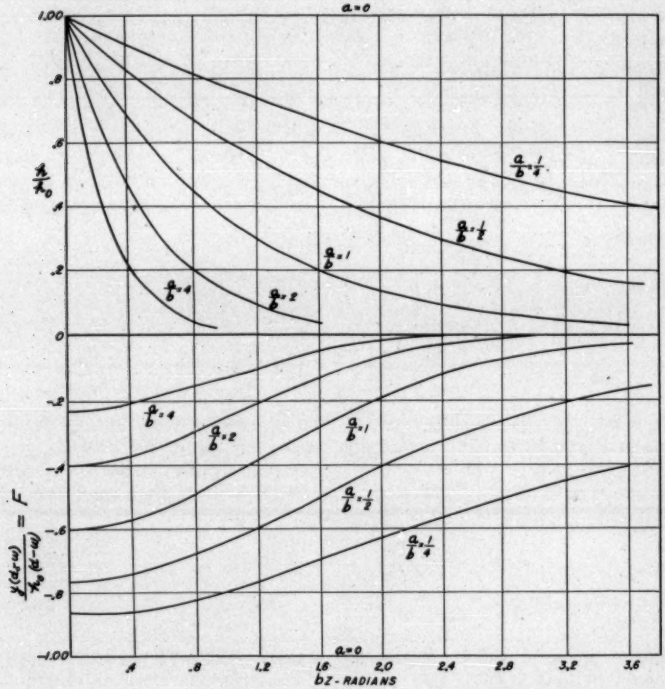

FIG. 2. Distribution of applied loads for various values of a/b and the resulting deformed figures of the lithosphere.

SUPERPOSED STRESS AND GRAVITY DEFECTS.

Employing the principle of isobaric equilibrium and using the stress function of Eq. (2), one may write the change in vertical stress S_v, due to the deformation produced by the imposed equivalent load as

$$-S_v = (d - w)gh_0(\epsilon^{-as} - F). \tag{14}$$

It is sometimes convenient, instead of thinking in terms of vertical stress, to define a stress height h_s such that the stress S_v alone will just support a prism of sediments of height h_s. Evidently therefore $-S_v = h_s(d - w)g$, or

$$h_s = h_0(\epsilon^{-as} - F). \tag{15}$$

It is interesting to note here that the ratio h_s/h_0 is dependent only on the geometry of the load. Figure 3 gives the ratio of stress height to initial load height for various geometries specified by different values of a/b as a function of the distance from the axis of symmetry expressed in radian measure. It should be observed that both the stress and the stress height change sign near the base of the mountain. Also, that h_s will be zero if isostasy rather than isobary prevails in the region.

Because this paper seeks to compare isobaric equilibrium with isostasy, it is illuminating to define another height h_q. This height may be called the "pseudo-isostatic height" and is the height at which material of density d will stand above the original level, if the mass per unit area inside the deformed region is adjusted to be exactly equal to

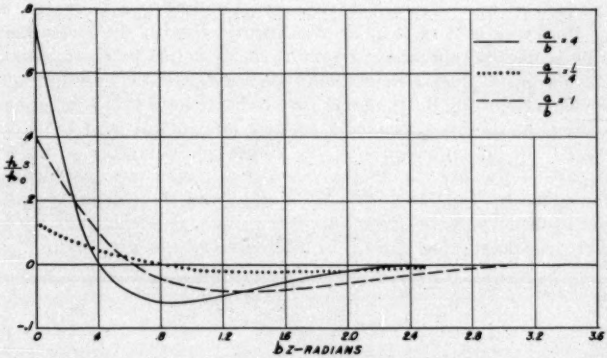

FIG. 3. Distribution of superposed vertical stress and gravity defects for various values of a/b.

that outside the region and if the lithosphere is deformed to the extent calculated above. The condition for constant mass per unit area is

$$y(d_0 - w) = (y + h_q)(d - w)$$

and, therefore,

$$h_q = \frac{d_0 - d}{d - w} y = h_0 \frac{d_0 - d}{d_0 - w} F. \tag{16}$$

By drawing in this pseudo-isostatic level for any deformed region, it is easy to visualize the distribution of excess or deficiency of mass. Differences in the actual heights above or below h_q imply a finite positive or negative gravitational defect. It is valuable to note from Eqs. (13), (15) and (16) that the stress height is the difference between the actual height and the "pseudo-isostatic height" or

$$h_s = h_a - h_q = \frac{-S_v}{(d - w)g}. \tag{17}$$

The change in gravitational acceleration Δg at a point on the axis and at a distance p above the top of a cylindrical plate of thickness h, radius R and density d is given by the approximate relation

$$\Delta g = 2\pi\gamma dh\left(1 - \frac{p}{R} - \frac{h}{2R} + \text{terms of higher power}\right), \qquad (18)$$

where γ is the gravitational constant. The change in acceleration at the summit, due to a long mountain of triangular cross section and of height h, may be shown to be a nearly similar expression

$$\Delta g = 2\varphi\gamma dh, \qquad (19)$$

where φ is the total vertex angle in radians. This evidently degenerates to Eq. (18) if the vertex angle is π, corresponding to a plateau. Now if the thickness of a large plate h is identified with the stress height, then by employing the above relations the principal topographical correction or gravitational defect may be evaluated. Thus, except for small corrections due for the most part to quite local mass distributions near the station, this gravitational defect is identical with the free air anomaly. In actual mountains the slopes are not large so that the main part of the free air anomaly is the principal topographical correction given by Eq. (18) provided h and d are the thickness and the change in density of the stress supported mass, respectively. By Eqs. (14), (17), and (18) and Eq. (3) of reference (2), one may write

$$\Delta g = 2\pi\gamma(d - w)(h_a - h_q)$$
$$= 2\pi\gamma(d - w)(\epsilon^{-az} - F)h_0 = -\frac{2\pi\gamma S_v}{g}. \qquad (20)$$

It is clear, therefore, that the representation of the distribution of stress height by Fig. 3 is typical also of the distribution of gravity defect. With a knowledge of the detailed topography and position, corrections may be applied to Eq. (20) and the acceleration due to an actual mass distribution calculated. This may then be compared with observation to determine the gravity anomaly. The first expression of Eq. (20) is most useful in evaluating the gravity defect in rugged mountain chains because it is usually not difficult to determine the value of $h_a - h_q$.

By aid of Eqs. (6), (3) and (10), one may readily calculate the load per unit area applied to the lithosphere and also the restoring stress applied by the supporting magma immediately below. The difference between these loads is necessarily carried by the strong lithosphere. The ratio of the restoring stress applied by the weak substratum immediately below to the superposed load stress is evidently the fraction of the load carried by the asthenosphere. Moreover, the fraction of the load carried by the lithosphere is one minus this ratio. The ratio is

important because it measures the approach of any given load to isostatic equilibrium. If the substratum carries all the load, the ratio is unity and ideal isostasy prevails. If the load is carried entirely by the strong lithosphere and distributed to the substratum over a large area, the ratio is zero and the compensation is zero. It is enlightening, in view of the foregoing facts, to plot the fraction of the applied load stress transferred to the immediately underlying weak asthenosphere as a function of the linear dimensions of the load. The values of this ratio for a logarithmic type mountain whose semidimension is measured by $1/a$, and for the center of a superposed block of uniform thickness are given in Fig. 4. The average value of the fraction for an entire block is also plotted for reference. From Fig. 4 it may be seen that typical

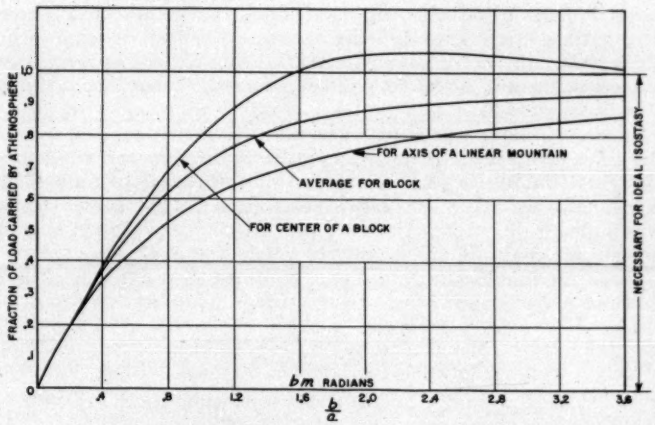

FIG. 4. The fraction measuring the degree of approach to isostasy as a function of the semi-linear dimension of the superposed load.

mountains are not in complete isostatic equilibrium and that the smallest size of block that can be in substantial isostatic equilibrium (ratio 0.96) corresponds to $bz = 1.4$, and from this it is found that the total width must exceed 330 km.[2] An exception exists when the lithosphere is completely fractured and it is then possible for a block approximately 100 km. wide to be in isostatic adjustment.

RELAXATION AND FIBER STRESS.

Contemporary geological opinion appears to favor the idea that stresses existing in the earth's crust are systematically relieved as time goes on and therefore isostasy will ultimately represent the final equi-

librium state. Because of this prevailing impression, it seems of interest to mention those natural processes which tend to drive all geological formations toward such an equilibrium state. One of the important factors, of course, is erosion of the highlands and the consequent deposition of sediments at the base of the mountain. Such a process will inevitably change the figure of the mountain and cause "a" to decrease as time goes on. Ultimately, if the mountain is eroded to a plane and if this plane is of sufficient extent, then the foregoing analysis shows that isostatic equilibrium will be finally established.

No very good way is available for determining the effect of rock creep or relaxation on geological structures. One may observe, however, that the modulus of elasticity E represents the ratio of stress to strain. Given a certain configuration, the stresses are determined, and if the material of the lithosphere continues to flow under this stress, one may note that the strain steadily increases and the effective value of E for this case steadily decreases with time. From Eq. (5) it may be seen that the value of b, therefore, will be increased. Thus again, the ratio a/b will be decreased and the region will tend toward isostatic adjustment. It may be generally concluded then, that natural erosion or relaxation processes both tend to reduce the superposed stress in the lithosphere, and it is conceivable that if the period of time is great enough, isostasy may ultimately be established. The present calculations indicate that this period of time must be very long indeed compared to the geological age of the Hawaiian Islands.

From the fundamental theory of deformed elastic beams, it is well known that the stress in the extreme fiber is given by

$$S_f = \frac{ET}{2}\frac{d^2y}{dx^2}. \tag{21}$$

By twice differentiating Eq. (10) and substituting in Eq. (21), the fiber stress is found to be

$$S_f = \frac{ETh_0da^2}{2d_0\left(1+\frac{1}{4}\left(\frac{a}{b}\right)^4\right)}\left[\epsilon^{-az} - \left(\frac{1}{2}\frac{a}{b}+\frac{b}{a}\right)\epsilon^{-bz}\cos bz + \left(\frac{1}{2}\frac{a}{b}-\frac{b}{a}\right)\epsilon^{-bz}\sin bz\right]. \tag{22}$$

In most cases of geological importance, the maximum stress is very near the origin where z equals zero and, therefore, it is easy to calculate by Eq. (22) its maximum value. The top of the lithosphere here is in compression while the bottom is in tension. Attention is drawn to the fact that the maximum stress is proportional to h_0da^2 and, therefore, one may expect to find the maximum stress in the lithosphere at points where large concentrated loads exist.

TEST OF ISOBARIC EQUILIBRIUM IN THE HAWAIIAN ISLANDS.

Because the principle of isobaric equilibrium has never been applied to a specific case, it is the purpose of the present paper to demonstrate its usefulness in describing the deformation of the lithosphere and gravity anomalies in an actual geological region. Since the calculations are necessarily based on a consideration of long linear distributions of superposed load, one picks for study the closest actual approximation possible to a long linear mountain chain consisting of a single ridge uncomplicated by subsidiary deposits on its outer edges. Moreover, to emphasize the remarkable aspects of isobaric equilibrium, it is desirable to select a region in which the width of this range is much less than 330 kilometers.

The Hawaiian Island chain satisfies most of the necessary requirements because it is essentially a linear mountain of volcanic origin and stands practically isolated in mid-Pacific. A good deal is known about its geological characteristics and some gravity data are available both on the chain and in the ocean nearby. Moreover, the geological evidence suggests that subsidence has been small during the present epoch.

The equivalent Hawaiian ridge suitable to be compared with the idealized mathematical calculation was determined by the following procedure: A line was drawn along the axis of the islands extending from Mt. Waialeale on Kauai to Mt. Kukui on the island of Maui. At right angles to this axis a wide section was considered extending from the western end of Kauai to the eastern end of Maui. The island of Hawaii proper was not considered because it is definitely off the principal axis and has such a large dimension that it cannot properly be classed as a part of a simple ridge. The effective area of the islands within the above described sector was determined at 2000 fathoms, 1000 fathoms and at sea level. These areas were divided by the length of the sector. In this way an average width for the equivalent Hawaiian ridge was deduced for three known levels. The profile of this equivalent ridge is plotted in Fig. 5. The ridge is essentially triangular in cross section and has an altitude of about 5.0 kilometers above the ocean floor and a base width of approximately 127 kilometers.

The constants of Eq. (6), a and h_0, are picked to represent the observed Hawaiian ridge as accurately as possible. The constant "a" of Eq. (6) is determined by calculating the slope of the mountain at the origin and adjusting the value to fit the observed points by successive approximations. It turns out, quite remarkably, that the value of "a" thus determined approximates very nearly the best available value of "b," the characteristic lithospheric constant defined by Eq. (5). Data from reference (2) gave "b" a value of $8.4 \cdot 10^{-8}$ cm.$^{-1}$. Because the value of b is not known precisely, it is sufficient to assume that $a = b$ and carry through the analysis on this basis. The author knows no very good reason why the two constants should turn out so nearly the

same. They are, however, both observed quantities and there is no known reason for doubting either.

With a knowledge of a/b determined from the observed figures, it is possible to evaluate Eq. (10) and plot the figure of the deformed lithosphere under the island ridge. One calculates first the value of Eq. (10) assuming that the entire chain is submerged in water of density $w = 1.03$. Superposed on this solution one adds a correction for the small section of the chain that is actually above water. This small correction is due to the triangular ridge 0.5 km. high having a semi-base width of 7.65 km. and a density of 1.03 or just sufficient to make up for the sea water assumed to be displaced in the basic calculation.

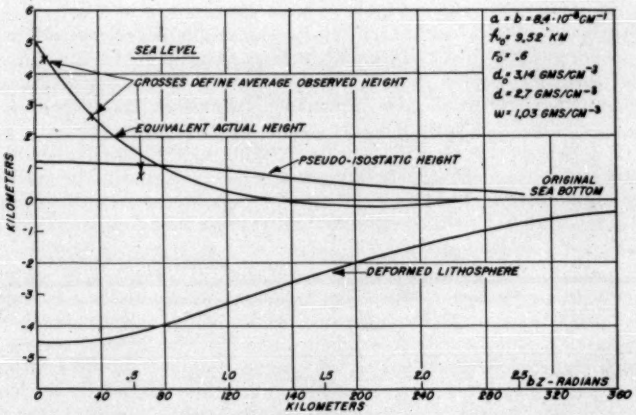

FIG. 5. The derived figures of load and lithosphere under the Hawaiian ridge. Observed figure indicated by crosses.

The densities of the islands are relatively unknown. No great error will be introduced, however, if the density of the ridge d is taken as 2.7 gms./cm.^{3} and that of the asthenosphere (following Heiskanen) as 3.14 gms./cm.^{3} at 50 km. depth. Substituting the above densities in Eq. (13) taking the actual observed height h_a above the ocean floor as 5 km. and evaluating F for $a/b = 1$, it is found at $z = 0$ that $h_0 = 9.52$ km. Thus, only a little more than half of the Hawaiian ridge rises above the ocean floor. Once h_0 is determined, the actual height and figure may be derived from Eq. (13) by taking $a = b = 8.4 \cdot 10^{-8}$ cm.$^{-1}$. These data are plotted in Fig. 5.

Similarly, the figure of the deformed lithosphere is determinable from Eqs. (10) and (11) and this also is shown in Fig. 5. Finally, on

this same figure is shown the "pseudo-isostatic height" h_q defined by Eq. (16). The superposed deformations due to the correction for the non-submerged portions of the island are scarcely discernible in the figure. Therefore, surface irregularities on the islands will have a still smaller effect.

The vertical stresses in the lithosphere are given by Eq. (14). Adopting the constants used in the foregoing paragraphs the vertical stresses are plotted in Fig. 6. It is important to note that the vertical stress reverses direction as one proceeds away from the axis. Near the center, the lithosphere imposes an upward vertical stress on the applied load while on the outer edges it imposes a downward stress on the supporting magma. The reader may verify from Eqs. (10), (11), (14), and

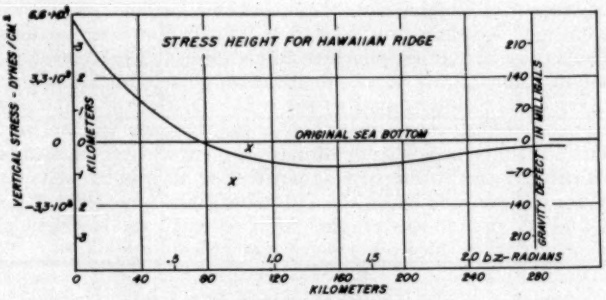

FIG. 6. The derived distribution of superposed stress and gravity defect for the Hawaiian ridge.

(21) that the positive area under the stress curve is equal to the negative area and that

$$\int_0^\infty S_z dz = 0 \qquad \text{or} \qquad \int_0^\infty \overline{\Delta g} dz = 0. \tag{23}$$

The stress curve of Fig. 6 also gives, by Eq. (20), the distribution of the gravitational defect for the ideal equivalent ridge. Therefore, Fig. 6 describes in general, but not in detail, the expected gravity anomalies of the Hawaiian area. Putting in the numerical constants of Eq. (20), an auxiliary scale may be determined for Fig. 6 that gives the principal term of the gravity anomalies. The gravity anomalies of the ridge are strongly positive out to about 80 km. from the axis of symmetry and are somewhat negative outside of that distance. It is interesting to note that the small area near where the stress is zero is in substantial isostatic equilibrium. Isobaric equilibrium, however, prevails throughout the region.

One now turns to a detailed calculation of the gravity anomalies that inevitably accompany the superposed vertical stresses in the lithosphere. From the form of Eq. (10) and the facts emphasized by Fig. 4, it follows that irregularities in the mass distribution near the top of the Hawaiian ridge will have little influence on the figure of the downward deformation, provided the total load is well evaluated. On the contrary, irregularities in the actual mass distribution near a station have an appreciable effect on the measured accelerations due to gravity. For example, the smooth gravity defect curve of Fig. 6 for the Hawaiian ridge gives the approximate magnitude and trend but is not useful in evaluating the gravity anomaly at a selected point. In order to evaluate easily actual gravity defects and anomalies, it is convenient to adopt the following procedure. First, one determines the logarithmic mountain that most closely represents the actual one. From this the pseudo-isostatic height is deduced by Eq. (16). This height is not at all sensitive to superposed mass irregularities and is a most useful reference base. This height defines the level at which the mass per unit area in the deformed region is exactly equal to the mass per unit area outside the deformation. Thus, actual prisms of rock above or below this level represent a surplus or deficiency of mass supported by a vertical stress and this produces an accompanying positive or negative gravity defect. In fact, the difference between the actual height of any selected gravity station and the pseudo-isostatic height is equal to the stress height h_s and this is related to the gravity defect and stress by Eq. (20). Therefore, in order to estimate the principal term of the gravity anomaly at any selected point in the Hawaiian Islands, one determines the change in mass per unit area for the rock lying above h_q and by Eq. (18) multiplies this by $2\pi\gamma$. Thus, if the height of a gravity station above the ocean floor is plotted as abscissa and the gravity defect is plotted as the ordinate, then a straight line through h_q, 0, and having a slope $2\pi\gamma(d - w)$, will describe the principal term of the anomaly at all levels. Since h_q, in general, changes with the distance from the axis of symmetry, it is clear that a family of slightly different straight lines having a common slope will describe the gravity defects throughout the region. Such a curve is plotted for the islands in Fig. 7. For this curve the original sea floor was adopted as the reference level; therefore, h_q was + 1.19 km. as calculated from Eq. (16), taking $d_0 = 3.14$ gms./cm.^{2}, $d = 2.7$ gms./cm., $w = 1.03$ gms./cm.^{3}, and $h_0 = 9.52$ km. On this curve are plotted all observed values in the applicable region for the free air anomaly as given by Meinesz.[3] The numbers attached to the points refer to his station numbers. The notable departures for stations Nos. 111 and 114 are for the most part due to the asymmetry of the ridge and to additional sediments that have washed into the depressions on each side.

[3] V. Meinesz, *Proc. Nederl. Akad.*, 44, 2, 1941.

In the present investigation only the free air anomalies are physically significant. Isostatic anomalies imply a type of compensation that is highly artificial except in level country where vertical stresses are negligible. Moreover, empirical adjustments are invariably made that are designed to reduce the magnitude of the anomaly to zero. This is not physically justifiable. The topographical corrections to be added to the principal one computed above are usually small and are valid provided arbitrary compensations are not assumed. The estimates of the gravity defects made above need a small correction for some of the details of topography before one may properly assume that they represent the true anomaly. In most cases this small correction will improve the agreement exhibited by Fig. 7. Estimates of the detailed topo-

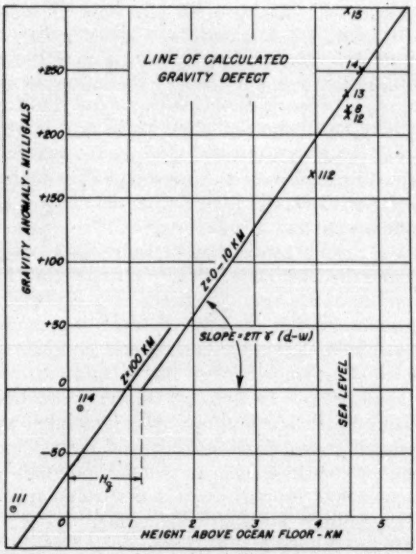

FIG. 7. Calculated and observed gravity anomalies in the applicable Hawaiian region.

graphic correction are tedious without the aid of elaborate tables like those prepared by Hayford and Bowie. But since the Hayford-Bowie tables are calculated with a compensation correction incorporated throughout, they may not be employed to determine the correction in the present investigation.

An inspection of Fig. 5 will show that the maximum local compensation for the Hawaiian ridge is only about fifty per cent. and that the

rest of its support is spread out to the side for a distance of 260 km. Meinesz [3] has examined the Hawaiian ridge employing the contemporary principles of isostasy and finds that the regional anomalies so calculated are a minimum if the compensation is spread out uniformly to a distance of 232 km. He concludes that his investigation "implies a rigid Earth crust of a large thickness." Meinesz' investigation leads to an approximate description that approaches the present one as nearly as is possible within the framework permitted by the requirements of regional isostasy.

Finally, one considers the thickness and strength of the Hawaiian lithosphere. The author's first paper on the lithosphere led to numerical values for its effective thickness, namely, 50 ± 15 km., and showed that imposed deformations were reduced to a small fraction of their initial value in distances approximating $1/b$ or 125 km. The present investigation shows that "a" for the Hawaiian chain very closely approximates "b." Further, because the calculated gravity defects depend critically upon the ratio a/b and because these defects agree well with observation, one may properly conclude that b for the lithosphere under the Hawaiian chain is substantially the same as it is under the deltas of the Nile and Niger rivers and the same as it is south of Java.[2] In other words, the lithosphere of the earth appears to be quite homogeneous and its overall elastic behavior is defined by the highly important lithospheric constant $b = 8.4 \cdot 10^{-8}$ cm.$^{-1}$.

Because of the circumstances outlined above, it is of particular interest to determine the strength of the crust under the Hawaiian chain. The stress at the extreme fiber S_f is given by Eq. (22). In this expression we adopt as the best available $E = 10^{12}$ dynes/cm.^{2}, $T = 5 \cdot 10^6$ cm., $h_0 = 9.52 \cdot 10^5$, $a = b = 8.4 \cdot 10^{-8}$ cm.$^{-1}$, $d = 2.7$ gms./cm.^{3}, $d_0 = 3.14$ gms./cm.^{3}, $z = 0$. Carrying through the calculation, it is found that the maximum stress is $S_f = 8 \times 10^8$ dynes/cm.^{2}. Although the lithosphere is in tension at the bottom, one must remember that the hydrostatic compressional stress there exceeds 10^{10} dynes/cm.^{2} so that the region is still under compression. In general, one may conclude that the lithosphere here will support one-sided stresses approximating 10^9 dynes/cm.^{2} for exceedingly long periods of time.

DISCUSSION.

In the foregoing paragraphs, we have undertaken a straightforward determination of the form and figure of a lithosphere distorted by a long mountainous load. The assumed figure of the mountain is capable of being adjusted to fit a variety of observed forms. The assumed conditions regarding the restoring forces and elastic behavior of the lithosphere appear to be physically realized and, provided the mountain range assumed for study is reasonably long compared to its width,

there is no reason to suppose that the derived figures are not relatively exact. Attention is drawn to the fact that these derived figures are independent of any assumption as to the existence of isostasy or isobaric equilibrium and rest fundamentally upon the elasticity of the lithosphere and the lack of strength in the underlying magma provided, only, that the restoring force is proportional to the downward displacement. An examination of the resulting deformations will show clearly that the mass per unit area near the deformed region is different from that outside. Therefore, it is clear that the fundamental requirement for the existence of isostasy is not fulfilled. However, close analysis shows that the deformation is consistent with the principle that the pressure over a gravitational equipotential surface is a constant. This basic principle that we have called the "principle of isobaric equilibrium" is more fundamental than isostasy and degenerates to it as a special case when $S_v = 0$. The resulting calculated figures of the lithosphere may be compared with a derived figure corresponding to constant mass per unit area. Thus the actual mass distribution may be compared with the distribution expected to produce no gravity anomalies. An excess of mass per unit area in the region leads to a positive gravity anomaly and a deficiency to a negative anomaly. As shown in Fig. 7, the agreement of the calculated anomalies employing this simple idea when compared with the observed free air anomalies is very satisfactory. The agreement is perhaps better than might be expected because of some uncertainty in the values for "a" and for "b."

One of the important problems connected with the properties of a lithosphere has to do with the reality of continental migration as outlined first by Taylor and by Wegner. Evidently, if it can be shown that the lithosphere is uniform and as strong as it appears to be in the Hawaiian Islands, then at least some of the details of the Taylor-Wegner hypothesis should be modified to the extent of admitting that the migration took place during the very earliest period of geological development. This is simply a recognition of the fact that the earth was possibly once semi-liquid and a strong lithosphere did not physically exist.

It is believed that the foregoing successful application of simple mechanical principles to the study and evaluation of gravity anomalies in the Hawaiian Islands shows the finite strength of the lithosphere plays a really important part in the support of such earth features. The rather detailed interrelation of the various determinable physical quantities leads to a consistent picture, and the author is inclined to the belief that the analysis pretty well duplicates the actual physical state. If this interpretation is correct, then it seems fair to insist that contemporary practices used by isostasists in assigning the amount and distribution of mass compensation for given earth features are quite arbitrary and not in agreement with the physical facts. The present

calculations show that the compensating masses which provide the support for a superposed earth feature are distributed by the lithosphere to a distance of about 250 kms. from that feature. The amount of local compensation depends critically upon the figure of the superposed load, so that it will be difficult to work out any general scheme of complete compensation analogous to that practiced in isostatic reductions. However, it should be emphasized that the present investigation only slightly affects contemporary studies of isostasy when these are applied to relatively undeformed regions where the vertical superposed stress is negligible. But in mountains or deformed regions, it appears that the basic principle of isostasy and associated practices employed to reduce the anomalies to zero are incorrect. Free air gravity anomalies represent physically real conditions deserving careful study. Their presence in special regions of the earth emphasizes the reality of the principle of isobaric equilibrium and the limited applicability of the isostatic principle. In a future paper the author hopes to consider the influence of a strong lithosphere on the anomalies near a continental boundary. It will be shown that the lithosphere in these regions approximates those characteristics derived above.

NOTES FROM THE NATIONAL BUREAU OF STANDARDS.*

NEW PHOTOMETRIC UNITS ADOPTED IN GERMANY.

Before the war interrupted normal international relations, plans had been made to introduce throughout the world on January 1, 1941, a "new" system of photometric units replacing both the international and Hefner systems. Progress in the negotiations directed to this end has been reported from time to time (*Technical News Bulletin 246*, October, 1937; *265*, May, 1939; *273*, January, 1940). An article by W. Geiss in the *Bulletin of the Swiss Association of Electrical Engineers* (**33**, 395, 1942) states that the formal change to the new system of units was made in Germany on the date previously set, although the practical transfer still involved some difficulties. Since factors for converting values from the Hefner system to the new one were not published until 1942, some doubt remains as to the extent of use of the new units in actual practice.

The change of units in practical use involves a fundamental difficulty which has delayed the general adoption of any one system. This is that the establishment of a basic unit for light of one color is only a partial solution of the problem. There must also be a uniform method for passing from that color to others; that method must be chosen somewhat arbitrarily since there is no ground for saying that any one method is correct. The two systems of units hitherto in use have differed not only in the magnitude of the basic unit, but also in the relation between lights of different colors.

The principles of the new system were accepted internationally in 1937. They are, first, to establish a basic unit by taking the brightness of a black-body radiator at the temperature of freezing platinum as 60 candles per square centimeter, and second, to pass from one color of light to others by use of the standard spectral luminosity factors which were originally established by the American Illuminating Engineering Society on the basis of measurements made at the National Bureau of Standards (*BS Sci. Pap.*, **19**, 131 (1923–24); S475) and have since been accepted by the International Commission on Illumination and the International Committee on Weights and Measures.

It was necessary, however, to have practical working standard lamps of various types calibrated according to this new system. In order to make sure that all countries would have concordant standards, lamps of several types were calibrated by the principal national labora-

* Communicated by the Director.

tories and compared. This work was to have been finished early in 1939 so that the new units could be put into use January 1, 1940, but it was delayed because questions were raised regarding the validity of the luminosity factors. These were not settled until the International Commission on Illumination met in June, 1939. Plans were then made to complete the comparisons of standard lamps and to introduce the new system in 1941. These plans were accepted also by the Advisory Committee on Photometry of the International Committee on Weights and Measures.

The outbreak of the war naturally prevented the international measurements as well as the meetings of the authoritative international bodies dealing with weights and measures. Consequently no general adjustment of units has been made. The changes necessary in countries using the present international system will be relatively small, but they will be slightly different in the various countries and for various types of lamps. Ratios to be used in conversion from Hefner units to the new system were published in 1942 by the German Illuminating Engineering Society (*Das Licht*, **12**, 35 (1942)). The light from the platinum standard (at 2,046° absolute temperature) is not greatly different in color from that of a carbon-filament lamp, and for such sources the "new candle" is stated to be equal to 1.107 Hefner candles. For vacuum tungsten-filament lamps operating at a color temperature of 2,360° the ratio becomes 1.14, while for gas-filled lamps at 2,750° it becomes 1.162.

In 1928 the International Commission on Illumination set up provisionally a similar set of factors as representing the relation between Hefner and international candles (or lumens) for various types of filament lamps. The three factors recommended were 1.11, 1.145, and 1.17 (the last being for lamps at 2,600° absolute). From comparison of these two series of conversion factors the item cited concludes that the transition from international to "new" units can be made in Switzerland without any changes in the established specifications for lamps or in recommendations regarding illumination.

REVISED STANDARD FREQUENCY BROADCASTS.

Standard frequencies are now being broadcast from the Bureau's new radio station, WWV, at Beltsville, Md. The service has been improved and extended so that it now includes: (1) standard radio frequencies, (2) standard time intervals accurately synchronized with basic time signals, (3) standard audio frequencies, (4) standard musical pitch, 440 cycles per second, corresponding to A above middle C.

This service makes widely available the national standard of frequency, which is of value in scientific and other measurements. Any desired frequency may be measured in terms of any one of the

standard frequencies, either audio or radio. This may be done by the aid of harmonics and beats, with one or more auxiliary oscillators.

The service is continuous at all times day and night. The standard radio frequencies are 5 megacycles (= 5,000 kilocycles = 5,000,000 cycles) per second, broadcast continuously; 10 megacycles (= 10,000 kilocycles = 10,000,000 cycles) per second, broadcast continuously; and 15 megacycles (= 15,000 kilocycles = 15,000,000 cycles) per second, broadcast continuously in the daytime only (i.e., day at Washington, D. C.).

All the radio frequencies carry two audio frequencies at the same time, 440 cycles per second and 4,000 cycles per second; the former is the standard musical pitch and the latter is a useful standard audio frequency. In addition there is a pulse every second, heard as a faint tick each second when listening to the broadcast. The pulses last 0.005 second; they may be used for accurate time signals, and their 1-second spacing provides an accurate time interval for purposes of physical measurements.

The audio frequencies are interrupted precisely on the hour and each 5 minutes thereafter; after an interval of precisely 1 minute they are resumed. This 1-minute interval is provided in order to give the station announcement and to afford an interval for the checking of radio-frequency measurements free from the presence of the audio frequencies. The announcement is the station call letters (WWV) in telegraphic code (dots and dashes) except at the hour and half hour when the announcement is given by voice.

The accuracy of all the frequencies, radio and audio, as transmitted, is better than a part in 10,000,000. Transmission effects in the medium (Doppler effect, etc.) may result in slight fluctuations in the audio frequencies as received at a particular place; the average frequency received is, however, as accurate as that transmitted. The time interval marked by the pulse every second is accurate to 0.000,01 second. The 1-minute, 4-minute, and 5-minute intervals, synchronized with the seconds pulses and marked by the beginning and ending of the periods when the audio frequencies are off, are accurate to a part in 10,000,000. The beginnings of the periods when the audio frequencies are off are so synchronized with the basic time service of the U. S. Naval Observatory that they mark accurately the hour and the successive 5-minute periods.

Of the radio frequencies on the air at a given time, the lowest provides service to short distances, and the highest to great distances. For example, during a winter day good service is given on 5 megacycles at distances from 0 to 1,000 miles, 10 megacycles from about 600 to 3,000 miles, and 15 megacycles from about 1,000 to 6,000 miles. Except for a certain period at night, within a few hundred miles of the station, reliable reception is in general possible at all times throughout the

United States and the North Atlantic Ocean, and fair reception over most of the world.

Information on how to receive and utilize the service is given in the Bureau's Letter Circular LC645, "Methods of Using Standard Frequencies Broadcast by Radio," obtainable on request. The Bureau welcomes reports of difficulties, methods of use, or special applications of the service. Correspondence should be addressed National Bureau of Standards, Washington, D. C.

DETERMINATION OF RADON.

In recent months interest has revived in the problem of preventing poisoning and other injuries from radium in plants engaged in painting luminous dials. This is a natural result of the great increase in this type of work for the manufacture of military equipment. Although the principles of protection are now well known, many new workers under foremen who have recently entered this field are engaged in applying radioactive paint and there is, therefore, an increased possibility of injury through ignorance.

In controlling this type of hazard two important physical measurements are required, as outlined in the Bureau's Handbook H27, "Safe Handling of Radioactive Luminous Compound." The radon content of the workroom air and of the expired breath of the individual workers must be determined. These measurements having been made, it is possible to ascertain on the one hand, whether the workroom air contains sufficient radon to constitute a hazard, and on the other, whether workers are taking any of the radium paint into their bodies.

The increased use of radium paint has been accompanied by a growing number of requests for measurements of radon, so that the Bureau has had to expand its facilities. Apparatus previously used for this purpose consisted of a sensitive string electrometer connected to an ionization chamber in which the sample of air was placed to measure the strength of the ion current which the radon in the sample produced. This ion current is proportional to the amount of radon present. To save time on the part of the operator, it was necessary to make this electrometer record its readings automatically. This required the use of a photographic film in a special camera, so that the results were not known until the film was developed and interpreted. Many other disadvantages combined to reduce the rate at which tests could be made, such as failure of insulators in humid weather, and the necessity for adjusting the sensitivity of the electrometer to the strength of each sample.

To speed up these tests and also to improve their accuracy a new method was developed by L. F. Curtiss and F. J. Davis. This is described in the September *Journal of Research* (RP1557). To make

clear the principle employed it should be explained that radon is a radioactive gas which emits alpha particles—helium atoms traveling at high speeds. It is these alpha particles that produce the ion currents in an ionization chamber, as mentioned above. Therefore, a method of counting the number of alpha particles per hour from a sample gives a value proportional to the amount of radon present in the sample. The authors have devised equipment by means of which this may be done and the number per hour printed automatically on adding-machine paper. First, all oxygen is removed from the sample, since this gas hinders the production of a sharp electrical pulse in the ion counting chamber. The gas sample, minus oxygen, is introduced into the chamber, which is a large can with an insulated rod projecting into the center. The can is connected to a source of voltage of the order of 1,000 volts.

Under the conditions just described each alpha particle results in a sharp voltage pulse on the central rod as the ions it produces in shooting through the gas are driven to the central rod by the voltage applied to the can. This occurs in an extremely short time—less than 0.001 second. This sharp pulse is easily amplified by a vacuum-tube circuit until the current is strong enough to operate a traffic recorder, such as is used to count vehicles on a highway. This device automatically prints the day of the week, the hour of the day and the number of alpha particles which have passed through the chamber at that hour. This provides the necessary data for computing, quite simply, the amount of radon present.

The new arrangement is so compact that 6 ion chambers can be operated in the space required for 1 ionization chamber with its electrometer and camera. Furthermore, no photographic process is involved and the final record is immediately available, thus saving considerable time. Insulation of moderate quality may be used throughout the new equipment, because it is only important that the current be large enough to insure its being counted.

CALCIUM CHLORIDE COMPOUNDS OF *D*-α-GLUCOHEPTOSE.

In support of the concept that sugars which have like configurations for the atoms comprising the pyranose ring have like properties, Horace S. Isbell and Harriet L. Frush have found that *D-glycero-D-gulo*-aldoheptose (formerly *D*-α-glucoheptose) resembles *D*-gulose: it forms crystalline compounds with calcium chloride, changes in the concentration of which shift in a marked degree the equilibrium which exists in aqueous solutions. It was shown that this shift when calcium chloride is added, is toward the, at present, unknown alpha-pyranose modification. The equilibrium optical rotation of *D-glycero-D-gulo*-aldoheptose in 4 per cent. aqueous solution in the presence of calcium

chloride varies according to the following relationship:

$$[\alpha]_D^{20} = -20.2 + 3.54m - 0.067m^2,$$

in which m is the grams of calcium chloride per 100 ml. of solution. A crystalline compound, *β-D-glycero-D-gulo*-aldoheptose·$CaCl_2 \cdot 2H_2O$, was prepared and its mutarotation was measured. In 4 per cent. aqueous solution

$$[\alpha]_D^{20} = -6.5 \times 10^{-.0072t} - 9.3.$$

The *Journal of Research* for September (RP1555) should be consulted for the complete report of this investigation.

PROPERTIES OF BUNA S WITH GILSONITE.

A study of the electrical and mechanical properties of compounds of Buna S with gilsonite was undertaken a short time ago with a view to the utilization of these compounds for insulating wires and cables. The low power factor and capacitance of Buna S favor its use as insulation for communication lines, but without the addition of filler it is too weak and tears too readily to be of practical value. Carbon black, as a filler, has been shown to develop mechanical strength in Buna S, but it also raises the power factor and dielectric constant. The resulting compound is then unsuitable for insulating communication cables. This loss of electrical quality may be avoided and fair mechanical strength is developed when the hard asphaltite, gilsonite, is employed as a filler instead of carbon black, according to results reported by A. H. Selker, A. H. Scott, and A. T. McPherson in the September number of the *Journal of Research* (RP1554). Gilsonite, a native asphalt-like rock, is available from domestic sources in quantities adequate to supply any reasonable demand.

A series of compositions varying from a Buna S base compound with no filler to one with 150 parts by weight of gilsonite per 100 parts of Buna S polymer was investigated. The highest tensile strengths were observed for compounds containing 40 parts of gilsonite by weights. This compound when vulcanized at 162° C. for 20 minutes had a tensile strength of 1,200 lb./in.^{2} and a tensile stress of 560 lb./in.^{2} at 200 per cent. elongation. Prolonged vulcanization caused little change in either mechanical or electrical properties. The temperature of embrittlement of this compound was − 53° C., which is of the same order as that of the commercial insulating compounds.

The dielectric constant of a pure gum compound of Buna S was 2.88 at 100 cycles per second and was 2.78 at 100,000 cycles per second. The corresponding values of the power factor were 15×10^{-4} and 145×10^{-4}, respectively. With increasing amounts of gilsonite, the changes with frequency became smaller, about in proportion to the amount added.

The water absorption of the Buna S polymer used in this investigation was so high that it was unsuitable for some types of electrical insulation. This was probably the result of impurities remaining in the polymer from manufacturing operations, since it was produced early in 1942 and was known to contain a relatively large percentage of soap. Extraction of the crude synthetic by prolonged soaking and washing with water before compounding effected a significant improvement.

Except for water absorption, most of the requirements of the United States Coast Guard specifications for submarine and underground cable are fulfilled by a Buna S-gilsonite compound. The load required to produce compression cutting was 1,000 lb. as compared with the specified value of 650 lb.; resistivity was 3×10^{15} ohm-cm. as compared with requirements varying from 1 to 6×10^{15}. While the tensile strength was a little lower than specified, the modulus of elasticity was higher and the dielectric strength as well as other electrical properties were as required.

PROPERTIES OF CAST RED BRASS.

As the concluding phase of an investigation of red brass (Cu, 85; Sn, 5; Zn, 5), the effects of gaseous "impurities" were studied. The following gases were used as the enveloping atmospheres during the melting and pouring of the different heats: Hydrogen, nitrogen, methane, carbon dioxide, carbon monoxide, and air. Tests were conducted on the cast specimens to determine the tensile properties, hardness, density, electrical resistivity, running quality, and resistance of the finished casting to leakage under hydraulic pressure. The effects of the ambient atmosphere on the tensile properties, hardness, density, and electrical resistivity of red brass were somewhat different for the sand-cast specimens than for chill-cast specimens. These properties of the sand-cast bars, in general, were inferior to those of the other set. For both the sand-cast and chill-cast bars, hydrogen and methane had deleterious effects. The effect of hydrogen was most pronounced and detrimental. Microscopic examination revealed a high degree of unsoundness (voids) of the metal which had been melted under hydrogen.

The complete account of this work will be published as a paper (RP1553) by H. B. Gardner, Research Associate of the Non-Ferrous Ingot Metal Institute, A. I. Krynitsky, and C. M. Saeger, Jr., in the September *Journal of Research*.

DEAD WEIGHT CALIBRATING MACHINES.

Testing machines for determining the strength and other properties of structural materials are liable to error as is every other weighing

mechanism. To meet the need for a convenient, accurate, and portable device for determining these errors the Whittemore-Petrenko proving ring was developed by H. L. Whittemore and the late S. N. Petrenko of the Bureau's engineering mechanics section. The proving rings, themselves, must be calibrated, and a dead-weight testing machine of 102,000 pounds capacity was installed at the Bureau in 1927. The widespread and growing use of proving rings for checking testing machines in service and for adjusting the weighing systems of new ones has greatly increased the calls on the Bureau for calibrating these rings.

Fifteen years' experience in using the dead-weight machine forms the basis of Circular C446, prepared by Bruce L. Wilson, Douglas R. Tate, and George Borkowski, and released a short time ago. In using the machine, as originally installed, it was found necessary to apply 8 or 10 different test loads to determine the relationship between the load and the readings of a calibration device. Although test loads to determine the relationship between the load and the readings of a calibration device. Although test loads from 2,000 to 102,000 lb. by 10,000-lb. increments could be applied, the machine was found to be inadequate for calibrating devices having capacities less than 100,000 lb.

A new and smaller machine was therefore installed, for test loads from 200 lb. to 10,100 lb. by 100-lb. increments. The large machine is now used for loads from 2,000 lb. to 111,000 lb. by 1,000-lb. increments.

The errors of the weights were determined after the machines had been in use for several years. The maximum error of any of the weights was less than 0.01 per cent. and it is believed that their stability is such that the errors will not, under normal circumstances, exceed 0.02 per cent. for a period of 10 to 20 years.

Copies of C446 are obtainable from the Superintendent of Documents, Government Printing Office, Washington, D. C., at 5 cents each.

THE FRANKLIN INSTITUTE.

CONRAD NEWTON LAUER

1869–1943

On motion, duly made and seconded, the following Preamble and Resolution were unanimously adopted by the Board of Managers of The Franklin Institute at its meeting held September 15, 1943:

In the death of Conrad Newton Lauer, The Franklin Institute has lost a valued member of its Board of Managers, and the City of Philadelphia a distinguished and useful citizen.

Born at Three Tuns, Montgomery County, Pennsylvania, November 25, 1869, he entered the field of industrial engineering, and prior to his death, August 2, 1943, had served as President and Director of the Philadelphia Gas Works Company, Vice-President and Director of the United Gas Improvement Company, a Director of the Welsbach Company, of Baldwin Locomotive Works, of Sharp and Dohme, Inc., and other important business enterprises.

He was a Trustee of Stevens Institute of Technology, the Beneficial Saving Fund Society, the Pennsylvania Academy of the Fine Arts, the Philadelphia Chamber of Commerce and other organizations of like standing and importance. He was a member also of many of the social and business clubs of Philadelphia. He was the author of "Engineering in American Industry," and in 1930 received the honorary degree of M.E. from Stevens Institute of Technology.

Mr. Lauer joined The Franklin Institute in 1911, and became a member of its Board of Managers in April 1936. He was a member of the Friends of Franklin, and Chairman of the Vermilye Committee from November 1937 to December 1942, in which year ill health necessitated his retirement from the various committees in which he had been both active and helpful.

RESOLVED: That the Secretary extend to the children of Mr. Lauer the sincerest sympathy of the members of the Board, and that a copy of this Preamble and Resolution be sent them in evidence of the affectionate esteem with which their Father was regarded.

CHAS. S. REDDING,
President.
HENRY B. ALLEN,
Secretary.

September 15, 1943.

TWO NEW AWARDS TO BE GIVEN BY THE FRANKLIN INSTITUTE

At its September meeting the Board of Managers of The Franklin Institute voted to accept jurisdiction over the award of the following Medals:

The Clamer Medal founded under the terms of the will of Francis J. Clamer, to be awarded "for meritorious achievement in the field of metallurgy."

The Medal, of silver, will bear the above inscription on one side and on the other "Presented by The Franklin Institute of the State of Pennsylvania." It is to be awarded, not less than once in five years, upon recommendation of the Institute's Committee on Science and the Arts.

Francis J. Clamer was a co-founder of the Ajax Metal Company in 1880 and during his lifetime a distinguished metallurgist. He was the father of Dr. G. H. Clamer, also outstanding in the field of metallurgy; now President of the Ajax Metal Company, a member of the Board of Managers of The Franklin Institute and in 1904 the recipient of the Institute's Cresson Medal for 'methods of eliminating metals from mixtures of metals.'

The Newcomen Medal named for Thomas Newcomen (1663–1729), noted for the invention of a steam engine which bears his name and which pointed the way for the so-called industrial revolution with its uncounted benefits to man's progress.

The Medal, of gold, will bear around the top the inscription, "The Newcomen Medal," and at the bottom, "Founded by The Newcomen Society of England." In the center will be inscribed, "Awarded by The Franklin Institute of the State of Pennsylvania to ..... for achievement in Steam." The reverse side displays the seal of The Newcomen Society. It is to be awarded not oftener than once in three years, upon recommendation of the Committee on Science and the Arts.

The Newcomen Medal was founded by the American Branch of The Newcomen Society of England and will be awarded at the annual Franklin Birthday meeting of that organization at The Franklin Institute held on January seventeenth.

With the addition of these two Medals to the awards of the Institute, the total number is brought up to twelve. The two new medals are important in that they represent fields not specifically covered by other awards.

Recommendations of candidates for these and the other Institute Medals are welcomed and should be forwarded to the Secretary.

LIBRARY NOTES.

The Committee on Library desires to add to the collections any technical works that members would wish to contribute. Contributions will be gratefully acknowledged and placed in the library. Duplicates received will be transferred to other libraries as gifts of the donor.

Photostat prints of any material in the collections can be supplied on request. The average cost for a print 9 × 14 inches is thirty-five cents.

The library and reading room are open on Mondays, Tuesdays, Fridays and Saturdays from nine o'clock A.M. until five o'clock P.M., Wednesdays and Thursdays from two until ten o'clock P.M.

RECENT ADDITIONS.

AERONAUTICS.

Aircraft Year Book for 1943.

BIOGRAPHY.

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CHEMISTRY AND CHEMICAL TECHNOLOGY.

Institution of Chemical Engineers. Transactions. Volume 31. 1941.
LOESECKE, HARRY W. VON. Drying and Dehydration of Foods. 1943.
SCHOENGOLD, MORRIS D. Encyclopedia of Substitutes and Synthetics. 1943.

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ELECTRIC ENGINEERING.

CHUTE, GEORGE M. Electronic Control of Resistance Welding. First Edition. 1943.
CLARKE, EDITH. Circuit Analysis of A-C Power Systems. Volume I. 1943.
MORGAN, ALFRED P. First Principles of Radio Communications. 1943.
PUCKLE, O. S. Time Bases (Scanning Generators). 1943.

ENGINEERING.

MILLS, ADELBERT P. Materials of Construction. Fifth Edition, Rewritten and Edited by Lloyd F. Rader. 1939.
SINGLETON, JACK. Manual of Structural Design. Second Edition. 1943.
U. S. Work Projects Administration for the City of New York. Tables of the Moment of Inertia and Section Modulus of Ordinary Angles, Channels, and Bulb Angles with Certain Plate Combinations. 1941.

GEOLOGY.

American Institute of Mining and Metallurgical Engineers. Transactions. Petroleum Division. Petroleum Development and Technology. 1943.

MANUFACTURES.

ALLEN, HUGH. The House of Goodyear. 1943.
American Paper and Pulp Association. The Dictionary of Paper. 1940.
LAMPREY, L. The Story of Weaving. 1939.
National Bureau of Economic Research. Textile Markets. 1939.

MATHEMATICS.

U. S. Bureau of Standards. The Hypergeometric and Legendre Functions with Applications to Integral Equations of Potential Theory by Chester Snow. 1942.
U. S. Work Projects Administration for the City of New York. Table of Arc Tan X. 1942.
U. S. Work Projects Administration for the City of New York. Table of Natural Logarithms. Four Volumes. 1941.
U. S. Work Projects Administration for the City of New York. Table of Sine and Cosine Integrals. 1942.
U. S. Work Projects Administration for the City of New York. Tables of Circular and Hyperbolic Sines and Cosines for Radian Arguments. 1939.
U. S. Work Projects Administration for the City of New York. Tables of Probability Functions. Volume I. 1941.
U. S. Work Projects Administration for the City of New York. Tables of Sine, Cosine and Exponential Integrals. Two Volumes. 1940.
U. S. Work Projects Administration for the City of New York. Tables of Sines and Cosines for Radian Arguments. 1940.
U. S. Work Projects Administration for the City of New York. Tables of the Exponential Function e^x. 1939.

METALLURGY.

BAIN, EDGAR C. Functions of the Alloying Elements in Steel. 1939.
SEITZ, FREDERICK. The Physics of Metals. 1943.

MILITARY ART AND SCIENCE.

MACLEAN, NORMAN F., AND EVERETT C. OLSON. Manual for Instruction in Military Maps and Aerial Photographs. 1943.
ROBINSON, CLARK SHOVE. Thermodynamics of Firearms. 1943.

NAVAL ART AND SCIENCE.

Brassey's Naval Annual. 1943.

PHOTOGRAPHY.

RICHARDSON, F. H. Bluebook of Projection. Seventh Edition. 1942.

PHYSICS.

U. S. Work Projects Administration for the City of New York. Miscellaneous Physical Tables. 1941.

WHITE, MARSH W., Editor. Practical Physics. 1943.

SUGAR.

GILMORE, A. B., Editor and Publisher. The Louisiana Sugar Manual. 1943.

ERRATUM.

In Volume 236, No. 3, page 322, the book reviewed under the title "The Rise of the Petroleum Industry," by Malcolm MacLaren, should be entitled "The Rise of the Electrical Industry in the Nineteenth Century."

NOTES FROM THE BIOCHEMICAL RESEARCH FOUNDATION.

DR. ELMER O. KRAEMER of the Biochemical Research Foundation died suddenly while attending the 1943 Annual Meeting of the American Chemical Society at Pittsburgh. Overcome at luncheon on September 7th, he died at St. Joseph's Hospital, Pittsburgh, on the same day without regaining consciousness. Unheralded by any illness his sudden

ELMER O. KRAEMER

death, just after a short stay with his parents in Madison, Wisconsin, came as a severe and unexpected blow to his family, his fellow workers and to the world of science. We of the Biochemical Research Foundation mourn the loss of an admired and respected leader, a true friend and adviser whose willing help and wise counsel will be keenly missed.

Dr. Kraemer was born in Liberty, Wisconsin, on February 27, 1898. In 1918 he received his B.S. degree from the University of Wisconsin. He remained there as instructor working with the late Prof. Louis Kahlenberg for his Ph.D. degree. In 1921 he was awarded an American Scandinavian Fellowship and spent a year of research on colloid chemistry with Prof. The Svedberg at the University of Uppsala, Sweden. He spent the latter part of 1922 and the early part of 1923 continuing colloid chemistry research with Herbert Freundlich at the Kaiser Wilhelm Institute for Physical Chemistry and Electrochemistry in Berlin before returning to Wisconsin. Most of the year 1923 was spent in work on the kino-ultramicroscope, and for part of that year he was Assistant to Professor Svedberg who was at that time visiting lecturer in colloid chemistry at the University of Wisconsin. A year later, 1924, he was granted his Ph.D. degree at the University of Wisconsin where he remained as National Research Council Fellow doing research work on the optical properties of gelatin sols. In 1925 Dr. Kraemer was appointed Assistant Professor of Colloid Chemistry, and for two years he and his research students continued to study the properties of gelatin. His university connections were severed in 1927 when he joined the staff of the Experimental Station of the E. I. du Pont de Nemours Company at Wilmington, Delaware, as the leader of a group of research workers studying both fundamental and industrial colloid problems. For eleven years, until May 1938, he remained with the du Pont Company during which time he became well known for his profound knowledge of colloid chemistry, both fundamental and applied, and for the outstanding contributions to colloid science published by him and his collaborators.

It was during this time that he was instrumental in introducing into the du Pont Company's Research Laboratories the first oil-turbine high speed ultracentrifuge which was ever installed and operated outside Professor Svedberg's Institute at the University of Uppsala, and for many years Dr. Kraemer was responsible for the research carried on with the use of this highly specialized tool of the colloid chemist.

From the founding, in 1927, of the Cancer Research Fund of the Graduate School of Medicine, University of Pennsylvania (later to become the Biochemical Research Foundation of the Franklin Institute), Dr. Kraemer was assistant to Dr. Hamilton Bradshaw on its Advisory Council, and also visiting consultant on colloid chemistry, bringing his expert knowledge and broad scientific outlook to bear upon biochemical and cancer problems.

Dr. Kraemer resigned from his position with the du Pont Company in May 1938, and a few months later left with his wife and two sons to spend a further year on colloid research with Professor Svedberg at Uppsala, having been granted a fellowship by the Lalor Foundation of Wilmington for this purpose. After having visited a number of the

more important European research laboratories on behalf of the Biochemical Research Foundation he took up residence at Uppsala to continue the ultracentrifuge study of gelatin. It was during this year that he collaborated with Dr. Svedberg, Dr. Pedersen and others in the writing of the book "The Ultracentrifuge" which appeared in both English and German editions just as the present war broke out.

This year spent in Sweden was undoubtedly one of the happiest of Dr. Kraemer's life. Having met the young American girl who was later to become his wife when she too was a graduate student at Uppsala University in 1921, the return to Uppsala with his wife and family had been keenly anticipated. Being back with his old professor, being in the laboratory where so much of modern colloid research methods have been developed and with the workers responsible for the developments, seeing his two sons settle down to the Swedish school system and do well both in school and in athletic activities, cycling with his family to old haunts, visiting the ancient places of Sweden all brought the greatest pleasure and much happiness to Dr. Kraemer.

Returning to Marshallton, Delaware, in the Fall of 1939 Dr. Kraemer took up full time duties with the Biochemical Research Foundation to supervise the physico-chemical research on biochemical colloidal systems. In addition to bringing his wealth of knowledge on scientific matters and placing them unstintingly at the service of his co-workers, his pronounced critical faculty and well-thought out opinions contributed enormously to the spirit in the Foundation's laboratory. His sincerity of purpose, his pleasant even-tempered disposition, his capacity for teaching others, his willingness to help others, to take pleasure in their successes and to sustain and cheer them when things just didn't go right, won for him the respect, admiration and friendship of all who were privileged to know him and work with him.

Because of his love of science and his sustained energy Dr. Kraemer sought much of his relaxation from research problems in editorial work, in writing, and in teaching. A clear, facile writer, he was the author of the section on Colloids in Taylor's "Treatise on Physical Chemistry" and was actively engaged in revising his section for the forthcoming enlarged edition of Taylor and Glasstone when death terminated his work. He was the author of two chapters on the chemistry of large molecules in the monograph published recently by Western Reserve University, Dr. Kraemer having been the authority chosen to deal with this subject in the series of lectures entitled "Frontiers in Chemistry" held there in 1942.

He was, at the time of his death, the editor of *Advances in Colloid Science*, one of the editors of the *Archives of Biochemistry*, a member of the editorial board for the Monographs on High Polymeric Substances and he was serving as consultant for a number of special Government committees concerned with the war effort.

Dr. Kraemer had been for many years actively interested in the University of Delaware and in 1940 had been appointed to the faculty as special lecturer in colloid chemistry. His special course in colloid chemistry attracted many, both students and graduate chemists in industry.

As is to be expected from so active a research worker, many publications in scientific journals stand to Dr. Kraemer's credit since his first paper in 1923 describing his work with Freundlich on the formation of manganese arsenate jellies. He enjoyed membership in many scientific societies and was frequently an active participant in important meetings taking particular delight in contributing to the specialized symposia on colloids and methods in colloid chemistry held at the New York Academy of Sciences. For his contributions to the world's scientific knowledge he was honored in 1938 by being listed among the 250 outstanding scientists by "American Men of Science." His work for the past five years had shown this honor to be well merited. It is singularly unfortunate that an untimely death has terminated his career.

BOOK REVIEWS.

HANDBOOK OF ELEMENTARY PHYSICS, by Robert Bruce Lindsay. 382 pages, charts and diagrams, 14 × 21 cms. New York, The Dryden Press, Inc., 1943. Price $2.25.

The title of this book may be misleading to those who would class it with the usual handbook, for it is definitely unusual, particularly in construction and method of presentation. But like all handbooks and texts its aim is to be a tool for use toward a better understanding. As to its construction—the work generally is divided into two parts, the first being a primer of general physics. This covers the mechanical properties of matter (dynamics and wave motion), the thermal properties of matter, the electrical, and the optical properties of matter. The second part contains an illustrated dictionary of terms commonly used in elementary physics. These are arranged in alphabetical order and the definitions include very helpful drawings. The illustrations of course are not attached to all of the definitions and the definitions are likewise more explicit in some cases than in others. Thus the definition of the electron microscope is brief and unaccompanied by an illustration, while the electrophorus is much more lengthy and is accompanied with an illustration.

The method of presentation is apparently the result of much thought and planning. In the first part of the book, great care is expressed in handling the student, who is assumed to have had a pre-college educational background. The text is descriptive in nature, of necessity referring to mathematics but omitting the formulas which are collected in a table in the Appendix, convenient for ready reference and review. The author takes the stand in defense of this method that we may as well admit the fact that it is perfectly possible to talk sense in physics without the economy of abstract symbolism, and experience shows that many students form more accurate initial notions about the subject if they are compelled to state the contact of concepts, laws, and principles in terms of the language of ordinary speech. However, he does not take the stand of insisting on one to the exclusion of the other.

The book is intended principally for use along with a standard text book of the conventional pattern. As such, its greatest value lies in the primer part, the chief objection to the dictionary of terms being in the terms themselves. Until students cover at least one-half of an elementary course in physics, widely used terms may not be a part of their vocabulary for the reason that the course of instruction may be so built as to suit certain types of students who may become confused at first by the use of many of the terms. As progress is made, the terms are brought forward and made familiar. Alphabetical arrangement too, offers obstacles sometimes in locating the desired term.

A good feature of the book is the inclusion in the appendix of a table of a chronological outline of the leading developments and discoveries in the evolution of physics from early times down to 1940. A bibliography of suggested reading is also included, under a subject classification. The subject index in the back covers both parts of the book.

Because this book is unusual in many ways, because of its many good features, it has a potentiality of usefulness that should be carefully examined by teachers and students alike.

R. H. OPPERMANN.

TREATMENT OF EXPERIMENTAL DATA, by Archie G. Worthing and Joseph Geffner. 342 pages, charts and diagrams, 15 × 24 cms. New York, John Wiley & Sons, Inc., 1943. Price $4.50.

In these days of dealing with higher accuracy in measurements, precision instruments and infinitesimally small particles moving at tremendous speeds there is much need to be able to express figures and data clearly with evidence of a knowledge of their value. Unless this need is met satisfactorily it is often the case that more harm is done than if the expression

had not been made. Engineers, especially, must understand a broad field of data expression in the form of tables, graphs, indexes etc. This book is the outgrowth of a course along these lines for graduate students.

The work opens with a discussion on representation of data by tables. Here tables are divided into three classes, i.e.: the qualitative class which includes tables indicating parallelism of theories or analogies; the statistical class in which some of the variables are expressed quantitatively while others, including the variable assumed independent, are not, and which includes such tables as the U. S. Census Reports, tables of equivalents, and the periodic table of the chemical elements; the functional class which shows one or more relations of the type $y = f(x)$. Specific rules are included for the construction of the latter, together with two simple methods of smoothing data. The important problem of interpolation is discussed, and several interpolation formulas are developed and illustrated and later there is a discussion of extrapolation. Representation of data by graphs is the topic next taken up. In this there are set forth the general advantages and purposes of graphical representation and illustrations are given of the simple qualitative type, then of the more important quantitative type. Finally, specific suggestions and rules are stated for the construction of graphs of the latter type.

The equation method of representing data is given considerable space. First equations involving one independent variable are treated, later periodic curves are discussed and after this distribution functions of statistical data. Bearing on the graphical method is the coverage here, of differentiation and integration, and similarly, bearing on the equation method is the coverage here of the Fourier Series. A knowledge of the law of frequency distribution is given which is valuable in determining what relation a measured value bears to a true value in quantitative experiments. In this treatment there are derived expressions for precision indexes and further following this thread, an expression is derived for the mean of a series of weighted measurements leading to methods for computing precision indexes from unequally or equally weighted readings. The latter part of the work is devoted to the adjustment of conditioned measurements, least squares equations representating observed data, correlation, and the analysis on non-harmonic periodic functions.

The coverage is detailed and thorough. The authors have carefully selected topics of practical importance and presented them in a logical progression. Everyone recording or using data of this nature should be familiar with the contents of this book.

R. H. OPPERMANN.

PUBLICATIONS RECEIVED.

Treatment of Experimental Data, by Archie G. Worthing and Joseph Geffner. 342 pages, charts and diagrams, 15 × 24 cms. New York, John Wiley & Sons, Inc., 1943. Price $4.50.

Fluid Mechanics, by R. C. Binder, Ph.D. 307 pages, charts and diagrams, 16 × 23 cms. New York, Prentice-Hall, Ind., 1943. Price $3.75.

General Physics, by Oswald Blackwood, Ph.D. 622 pages, illustrations and diagrams, 14 × 22 cms. New York, John Wiley & Sons, Inc., 1943. Price $3.75.

Electrical Engineering: Basic Analysis, by Everett M. Strong. 391 pages, charts and diagrams, 15 × 22 cms. New York, John Wiley & Sons, Inc., 1943. Price $4.00.

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CURRENT TOPICS.

Machine Gun With Plastic Bullets.—A machine gun, which uses plastic pellets and compressed air instead of expensive bullets and gunpowder, yet provides all the racket and recoil vibrations of a war-time anti-aircraft weapon, has been developed by engineers of the Edison General Electric Appliance Company for Uncle Sam to use in training his soldiers at less cost. This gun which operates by electricity, will fire 600 rounds of the plastic bullets per minute, the same rate as the 50-calibre Browning machine gun. Whereas 50 calibre bullets cost approximately 30 cents each, making the cost $180 per minute for operation of the Browning gun, the plastic pellets cost less than one cent each and can be used over and over again, with an occasional soap and water washing. The gun is built to actual size and appearance of the Browning type. It is handled exactly like one except that its operation is on a scale of 1 to 30. Thus when fired at miniature buildings and tanks or airplanes zooming across the sky at a distance of 50 feet it simulates firing an actual gun at 500 yards. Pellet velocity and trajectory are according to scale, hence the trainee learns correctly to "lead" a moving target and to aim his gun by the stream of white pellets which become fluorescent at night in the "black light" of an ultra-violet spotlight attached to the gun. Fluorescent targets are also used at night. Amplified "explosions" of compressed air accustom the trainee to the distractions of actual muzzle blast and the recoil, and recordings of dive bombers and other battle sounds produced by a loud speaker tend to eliminate the jitters he might otherwise experience in his first combat firing. The training gun can be used indoors or out. It can be mounted on standards for use on the ground or on a truck or combat car. Engineers perfected the gun sometime ago. Since then General Electric has made many which are now in use by trainees of Army anti-aircraft units, ground forces, mechanized and air forces in camps all over the country.

R. H. O.

ARMY AND NAVY NOTES.

The Camera Lucida as an Aid in Aerial Photographic Mapping.—H. T. U. SMITH and H. J. PETERSON. (*The Military Engineer*, vol. xxxv, no. 214.) In planimetric mapping from vertical aerial photos, either by radial line method or by less exact methods, a moderate degree of enlargement or reduction is frequently necessary in transferring detail from the photo to the compilation sheet. This is commonly done by either interpolative sketching, or by the use of an overhead reflecting projector. The latter is preferable for precision work but has the disadvantage of high cost and lack of portability. It is possible, however, to obtain essentially the same results with the far more compact and less expensive camera lucida. This instrument is widely used in the biological laboratory and in general microscopy, but seems to have escaped the attention of photogrammetrists.

The camera lucida is a device which superimposes the images of two objects on the eye, causing the one to appear as though projected on the other. One of the two general types of the instrument involves the two objects at right angles. It consists simply of a transparent reflecting surface *O*, so arranged that the reflected image from one object *L* is presented to the eye at the same time as the transmitted image from the other object *R*. *L* and *R* are at right angles to each other through the reflecting surface *O* which is at the point of the right angle. The eyepiece or reflecting surface *O* may be either a very thin piece of glass, a half-silvered mirror, or a pinhole mirror. The principle is illustrated by the common experience of looking out of a window at an angle and seeing the reflection of some object within the room superimposed on the direct view of some other object outdoors. Glass, however, has a low reflecting power and is, therefore, less satisfactory than a partially silvered mirror; if it is used the light on *L* object must be much brighter than on *R*. This simple type of camera lucida has the one great disadvantage of reversing the reflected image, and is, therefore, suitable only for tracing either from a photographic negative, or on to a transparent sheet which itself may be reversed for reproduction.

The wollaston type of camera lucida avoids a reversal of the image by the use of a special doubly reflecting prism.

In using the camera lucida a photo and map sheet are used. A pencil point on the latter will appear to be resting on the former and any desired amount of detail may be traced. The instrument, of course, may be adjusted for enlargement depending on the distances traversed by the rays of light.

R. H. O.

Launching a Ship.—REAR ADMIRAL HENRY WILLIAMS, U.S.N. (*The Military Engineer*, vol. xxxv, no. 214.) Fom an engineering point of view, the launching of a ship is of technical importance and potential danger, which unless the calculations and details of procedure are carried out with care and judgment may result in disaster. Launching consists primarily of transferring the weight of the vessel from the blocks, shores and cribbing to the launching cradle and then allowing the ship and cradle to slide down the ground ways into the water. The launching calculations are taken in hand for a heavy ship before the vessel is laid down.

Forces involved during the launching are the forces of gravity acting through the center of gravity of the moving mass and of buoyancy acting through the center of buoyancy of the submerged portion, varying as the ship moves into the water. When the moment of the force of buoyancy around the forward end of the sliding ways becomes greater than the moment of the force of gravity around the same point, the stern of the vessel lifts, or "pivots." The pivoting load is the amount by which the weight of the vessel exceeds the buoyancy at this point. There results a concentration of load on the forward end of the launching ways, called the "fore poppet," requiring special construction and often internal shoring of the ship's structure to support this load, which may be 25 per cent. of the launching weight. If the buoyancy is insufficient, after the center of gravity of the ship has passed beyond the end of

the ground ways, the ship will tip downward at the stern, thus bringing concentrated pressure on the way ends and on the bottom of the ship at the point. The effort is to secure adequate depth of water over the way ends to ensure sufficient buoyancy to lift the stern of the ship. If the buoyancy is not adequate to support the ship when the fore poppet passes the end of the ground ways the bow will drop and damage may result from striking bottom. The motion of the ship along the launching ways is due to the component of the force of gravity: $W \sin \theta$ where W = weight of vessel as launched (including cradle) and θ = angle of inclination of the ground ways. This movement is resisted by friction which is: $fW \cos \theta$, f being the coefficient of friction between the sliding ways and the ground ways. In order that the vessel will move, the condition represented by the following equation must obtain: $W \sin \theta > fW \cos \theta$ or $f < \tan \theta$. The values of the coefficient of friction that may be expected under the usual conditions of launching are well known. Thus the minimum admissible value of the angle of inclination of the launching ways is determined.

R. H. O.

Enemy Weapons.—COL. SCOTT B. RITCHIE. (*Army Ordnance*, vol. xxv, no. 139.) On all battlefronts American ordnance is being tested in deadly combat against the greatest array of enemies to oppose us in all history. Our enemies are shrewd and able. We may be certain that they are doing everything in their power to develop new weapons, to spring surprises and to improve the effectiveness of their existing equipment. Likewise it is absolutely vital for us to maintain our lead in fighting tools and we must obtain and utilize detailed engineering information on enemy ordnance.

The necessity for systematic organization to accomplish this mission was early realized. The framework for this consists of (1) a small unit in the Service Branch, Technical Division, Office of Chief of Ordnance, to supervise and coördinate the project as a whole; (2) an organization at Aberdeen Proving Center to receive, catalogue and examine the foreign matériel returned for that purpose; (3) field agencies to collect and ship the matériel from the battlefields to Aberdeen; and (4) various governmental, commercial and private research organizations to make engineering tests and analyses. To date 336 German, 102 Italian and 67 Japanese weapons and ammunition of different types have been received at Aberdeen.

Analyses of enemy weapons have revealed interesting and significant trends in enemy ordnance. German weapons show evidence of typical Teutonic thoroughness and many years' planning for war. It would be a serious mistake to underrate German ordnance design and manufacture because of a few weaknesses. There is evidence that the Germans are constantly improving the design and manufacture of their weapons. An illustration of this is the increase in the amount of alloys in the armor used on the Pz. Kw. IV tank over that used in the Pz. Kw. III. Guns of increased firepower are appearing in tanks and on self-propelled mounts. It is very significant, however, that none of our investigations or reports from the front have revealed any "mystery weapon" or any weapon of firepower superior to standard American ordnance. The Germans are using such ersatz materials as plastics for gunstocks and steel for cartridge cases.

Italian weapons reveal the inadequacy of the Italian system. With few exceptions (notably the Breda machine gun) Italian weapons are copies of World War I models or more recent German and French designs.

In the design of fighting weapons, the Japanese have rightly been called "the amazing imitators." They have procured many weapons from various armament firms throughout the world and have copied others extensively. It is obvious that Japanese industry cannot mass-produce high-quality weapons over a long period of time to compete successfully with American weapons.

R. H. O.

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